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Environmental and Socio-Economic Considerations for Aquaculture in Jervis Bay, NSW

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OBJECTIVES:

- Integrate local physical/environmental data and methods used in monitoring programs for Australian shellfish aquaculture for the current Environmental Assessment for Jervis Bay.
- Develop a desktop study to collate and review existing background information on the biophysical variables of Jervis Bay and the physical and environmental components influencing the bay's circulation.
- Make an independent socio-economic assessment of sustainable aquaculture enterprises in Jervis Bay.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

The outcomes from this project will contribute to the development of the Jervis Bay Aquaculture Development Plan currently being drafted by IINSW (NSW Fisheries) for extensive shellfish cultivation precincts. Specifically this report outlines the environmental (biophysical) conditions in Jervis Bay that may be suitable for various shellfish species, the environmental constraints and monitoring protocols. In addition, important socio-economic factors to consider are provided in the context of Jervis Bay. The beneficiaries of this report will be governance agencies responsible for the management of aquaculture and natural marine resources, potential aquaculture enterprise proponents to determine the suitability and viability of the proposed precincts, and the local community to inform them of extensive aquaculture operations.

This report was proposed to assist in the preparation of a future Environmental Impact Study (EIS) towards the development of sustainable aquaculture in Jervis Bay, New South Wales (NSW), Australia. The report provides an overview of the potential for extensive aquaculture in Jervis Bay by considering a range of biophysical and socio-economic factors, both in Jervis Bay and other locations in Australia, for which comprehensive EIS studies have already been conducted (e.g. Twofold Bay).

Jervis Bay is one of the few ocean embayments in NSW that, like Twofold Bay, have many of the biophysical characteristics required for near-shore extensive aquaculture. Extensive mussel aquaculture (*Mytilus galloprovincialis*) was previously trialed in an experimental and pilot commercial lease in Jervis Bay, and demonstrated the potential for commercially viable shellfish farming. Therefore, I&INSW (NSW Fisheries) developed a draft Jervis Bay Aquaculture Industry Development Plan (JBAIDP) in 2009, identifying potential aquaculture precincts with a total area of 150ha in the bay.

This report provides background environmental and socio-economic considerations as a contribution towards the requirements for a full Environmental Impact Statement (EIS), prior to the finalization of the JBAIDP and formal establishment of lease areas. A range of factors are reviewed based on the ecological and hydrodynamic characteristics of Jervis Bay which may influence choices of potential species and production methods at the proposed lease sites. Biophysical and economic characteristics of five potential species were considered for production in Jervis Bay: Mussels (*Mytilus galloprovincialis*), scallops (*Pecten fumatus* & *Chlamys asperrimus*), Akoya pearl oyster (*Pinctada imbricata*), Sydney rock oysters (*Saccostrea glomerata*) and flat oysters (*Ostrea angasi*).

Jervis Bay's hydrodynamic and water quality conditions have the potential to support the cultivation of a wide range of native shellfish species. However the shellfish species and associated biomass that can be supported within the proposed lease areas, without adversely affecting farm productivity and the environment, depends largely on the carrying capacity, or food production and supply. Preliminary estimation of the carrying capacity is provided in this report and indicates that for high density species such as Sydney Rock Oysters, a standing adult stock of between 800 and >2000 tons is feasible across the identified lease precincts, depending on the hydrodynamic model used. For low density species such as pearl oysters, this value will fall to between 10 and 40 tons. These estimates can be determined more reliably with the collection of site specific physical and biological data, especially primary production, but they provide a ball park estimates for different species at the proposed lease precincts. Annual production of the different species will depend upon farm stocking schedules and grow out periods for the different species.

Information about environmental risk assessment considerations for different species and associated cultivation technology is provided. One of the key potential environmental impacts from shellfish cultivation results from bio-deposition effects, which can be managed by maintaining appropriate stocking densities. Calculations included in this report, based on rapid flushing rates (i.e., short residence times) and visual evaluation of the previous pilot mussel cultivation site, indicate that for the proposed lease areas, there are likely to be few impacts from bio-deposition based on typical sustainable stocking densities used elsewhere.

Further potential impacts include the non-intentional function of aquaculture installations as Fish Attracting Devices (FAD) through provision of new, artificial habitat. In the case of Jervis Bay Marine Park, the location of sanctuary zones in proximity to shellfish installations carries the risk of potentially luring fish out of protected zones into areas of higher fishing pressure. In contrast, the infrastructure may also serve to increase overall fish abundance as an artificial reef. Fishermen usually regard FADs as a benefit and fishing practices often change in response to aquaculture installations. Caution must be exercised in the context of a multiple-use Marine Park to ensure that increased fishing pressure around shellfish farms does not impact on fish assemblages in sanctuary zones of the Marine Park. Fish tracking or tag and capture studies can determine the potential for impacts in sanctuary zones.

Environmental monitoring programs are necessary for any marine aquaculture operations, however it is important to optimize cost-benefits and minimize unnecessary regulatory burden on shellfish enterprises while providing effective and sensitive monitoring. Monitoring protocols from 14 shellfish cultivation areas in NSW, other states and globally were reviewed to establish acceptable methods, standards and to identify the types of impacts that have been shown from shellfish farms. There is limited consensus on the most effective protocols for monitoring, in part due to unique local considerations. However, there are existing monitoring protocols established for shellfish farming in NSW and they are comparable with practices worldwide (total organic carbon and benthic invertebrate assessment). However thorough baseline sampling beyond these two parameters, at a large scale and prior to the establishment of leases is recommended for an adaptive, routine monitoring program. Further parameters to consider from a baseline and local context are reviewed.

This report includes recommendations for a range of economic approaches that could be considered by both management agencies and enterprise proponents towards environmentally and economically sustainable shellfish operations. Commercial operations need to take into account a range of market conditions; costs of on-shore infrastructure to support production; production costs and values/hectare of existing aquaculture enterprises; shellfish market trends; investment costs; opportunities for local direct-sale of shellfish products; smaller vs. larger enterprises; type of land-based infrastructure required (commercial wharf/jetty, and boat mooring facilities are currently limited in Jervis Bay); centralized processing facilities and multiple vertically integrated enterprises. From an economic perspective, cost-benefit models, such as those used by Treadwell (1991) and Weston (2001) in previous reports on feasibility of aquaculture production in NSW, could be updated with current information (e.g., 2010 farm gate-values and costs of production) to determine economic feasibility of different species. Information is provided on economic potential and risk parameters for the five species considered in this report. Potential niche market-branding from Jervis Bay is suggested as important considering the small scale of the proposed precincts. Product diversification by cultivating multiple species at the same lease sites may also reduce risks and increase profitability for growers.

Finally, Social Returns on Investment (SROI), such as the availability of fresh local seafood, increased recreation and tourism potential, employment and increased public awareness of the benefits of sustainable food production, account for non-monetary returns from local seafood production. This is of consideration for justifying the level of governance support for the development of the industry.

KEYWORDS: ***Aquaculture, shellfish, Jervis Bay.***

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1 DESCRIPTION OF THE PROJECT

1.1 Background and Need

Jervis Bay is one of three marine embayments in NSW that possess the physical, geographical and ecological characteristics considered suitable for near-shore extensive aquaculture. Jervis Bay has a history of aquaculture, but only at experimental or pilot commercial scales. However, the success of small aquaculture trials has raised interest in establishing formal commercial leases. There are provisions in the Marine Parks Act and the Jervis Bay Marine Park Operation Plan for extensive, non-fed aquaculture; however lease sites and suitable operations need to be identified. Extensive aquaculture is defined in the Jervis Bay Aquaculture Industry Development Plan (JBAIDP) as the cultivation of species which can be grown without the use of artificial feed inputs.

In consideration of the need for multi-level government approvals, consultation with cross-sectoral stakeholders and a range of environmental considerations, the establishment of aquaculture in Jervis Bay is complicated and has proven to be a barrier to establishment of commercial operations. In recognition of this barrier, NSW Fisheries of I&INSW has taken the lead in establishing the JBAIDP, which will provide the framework for establishing extensive aquaculture in Jervis Bay. The Fisheries Management Act 1994 (FMA) mandates that aquaculture permits cannot be granted, unless an aquaculture proposal is consistent with the relevant AIDP.

A draft AIDP was prepared in 2009 for Jervis Bay, and will be developed to a final plan in order to ensure that any aquaculture proposals are consistent with minimum performance criteria and best practice standards. The final JBAIDP will also be used to determine the environmental assessment and monitoring protocols required for extensive aquaculture in Jervis Bay under the Environmental Planning and Assessment Act 1979. To date, the draft AIDP has identified locations in Jervis Bay that might be most suited for aquaculture leases considering Naval operations and Marine Park zoning, as well as other existing operations and public uses of the bay (Figure 1).

1.2 Objectives

The objectives motivating this study were to:

- Integrate local physical/environmental data and methods used in monitoring programs for Australian shellfish aquaculture for the current Environmental Assessment for Jervis Bay.
- Develop a desktop study to collate and review existing background information on the biophysical variables of Jervis Bay and the physical and environmental components influencing the bay’s circulation.
- Make an independent socio-economic assessment of sustainable aquaculture enterprises in Jervis Bay.

Considering the scope of this study in relation to the draft AIDP, the objectives one and two were fully addressed, and section three provides a framework and key recommendations to support a future socio-economic assessment. The interests of the local indigenous communities were investigated, and the socio-economic and industry profile of the Shoalhaven regions were considered. In addition, economic frameworks for the viability of cultivations systems are provided.

1.3 Methods

I&I NSW have provided a draft Aquaculture Industry Development Plan proposing precincts that may be made available to extensive aquaculture leases in Jervis Bay. The AIDP takes into consideration the zoning within Jervis Bay Marine Park, commercial and recreational uses, public access and proximity to residential development, naval operations and protected habitats. As a result, two areas are proposed in the AIDP: Precinct 1- close to Vincentia (50 Ha) and Precinct 2- off Callala (100 Ha) (see Figure 1). The current zoning plan and operational plan for the Jervis Bay Marine Park allows for extensive long-line aquaculture (e.g., mussels, scallops, oysters) on no more than 2% (equivalent to 440ha) of the Jervis Bay embayment. The draft AIDP proposed sites only occupy 34% of the 440 ha (i.e. 150ha), or less than 1% of the Jervis Bay embayment, thus occupying a small footprint of the area potentially designated for shellfish leases.

Extensive aquaculture in Jervis Bay will require an Environmental Impact Statement (EIS) and will include additional criteria beyond those established at Two Fold Bay for extensive aquaculture leases as a result of Jervis Bay's designation as a Marine Park. In addition there will be unique environmental and socio-economic attributes that need to be considered, as differing from criteria already considered in the Twofold Bay EIS. Within the JBAIDP working group established by I&INSW, it was proposed that some of the requirements for an EIS framework needed to be addressed through a review of literature, current industry status and management and identification of knowledge gaps.

The methods employed here are therefore a desktop study using published literature and local historic documentation from government agencies in the Shoalhaven. Using some of the published data, calculations were done to determine the ecological carrying capacity of shellfish aquaculture at the precinct sites. Otherwise, environmental and ecological data was summarized in tables and synthesized with relevance to Jervis Bay.

In addition, the important indigenous interests in the region were considered in the socio-economic section. Other socio-economic considerations were identified from published literature on other aquaculture studies, and frameworks for socio-economic assessment were identified.

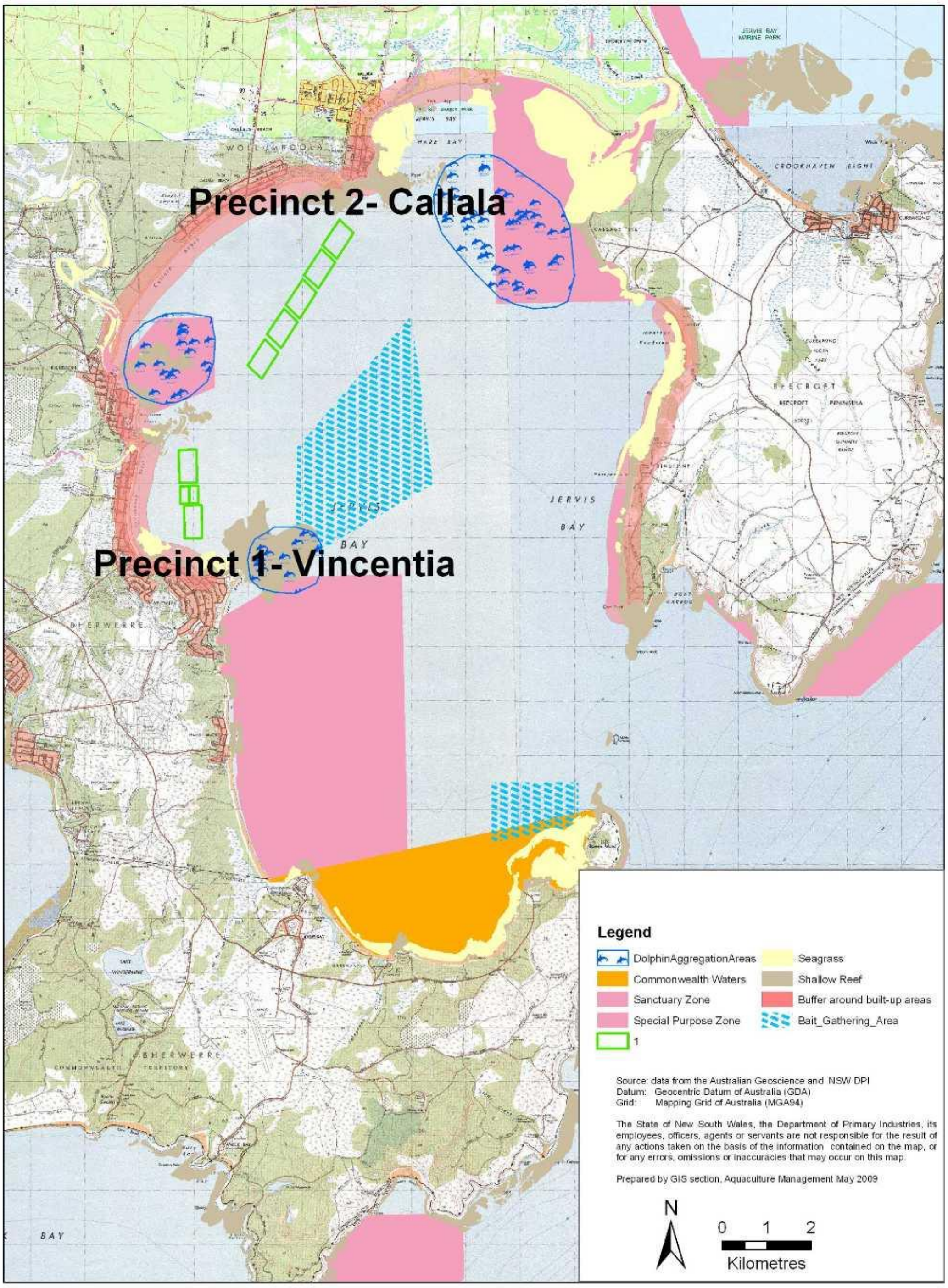

Figure 1-1 Location of proposed lease precinct areas (green outline) in Jervis Bay from the draft JBAIDP.

2 PROJECT SITE, JERVIS BAY

2.1 Geographic Location

Jervis Bay (35° 04’S 150° 44’E) is located on the East coast of Australia (Figure 2-1), approximately 150km south of Sydney in New South Wales and 20km southeast of Nowra in the Batemans marine bioregion. It spans over 100km of coastline and adjacent ocean extending from Kinghorn Point in the north to Sussex Inlet in the south. Population is concentrated on the Western foreshore of the bay in the towns of Hyams, Vincentia, and Huskisson.

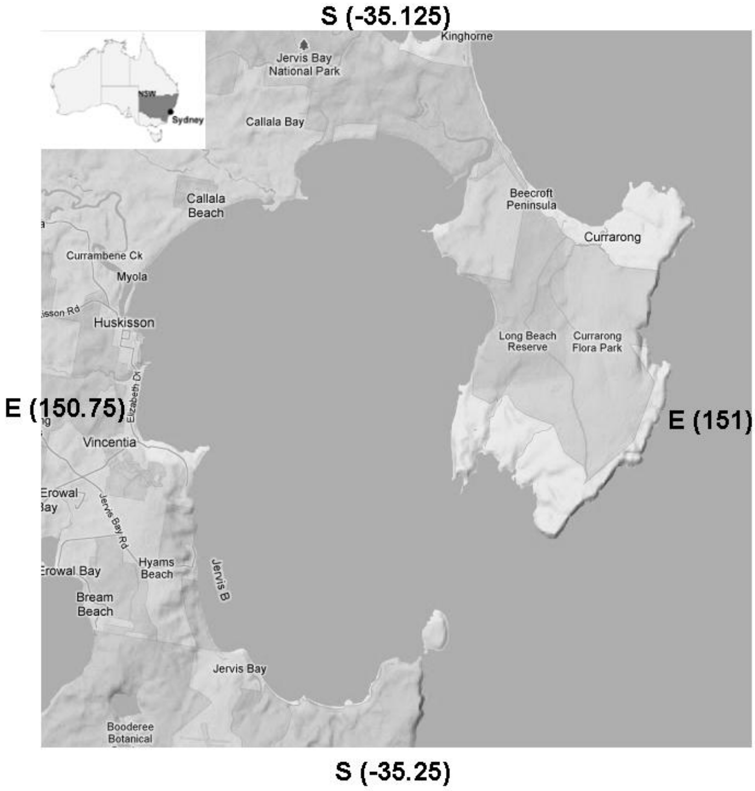

Figure 2-1 Geographic location of Jervis Bay

2.2 Biophysical Characteristics of Jervis Bay

2.2.1 Bathymetry and hydrology

The dimensions of Jervis Bay are approximately 15 km (north-south) and 8 km (east-west) with a total area of 124 km^2. The bay has a 3.5km narrow outlet to the ocean to the south east. The bathymetry of the bay resembles a bowl with increasing depth from the coastline to the middle of the bay, where maximum depth reaches 35m. The bay is relatively deep at its entrance (e.g., 40-50m at the mouth), with a shoaling bathymetry that results in shallow waters at the northern half of the bay (Table 3-1). Average depth across the bay is 20m (Craig and Holloway 1992; Wang and Wang 2003).

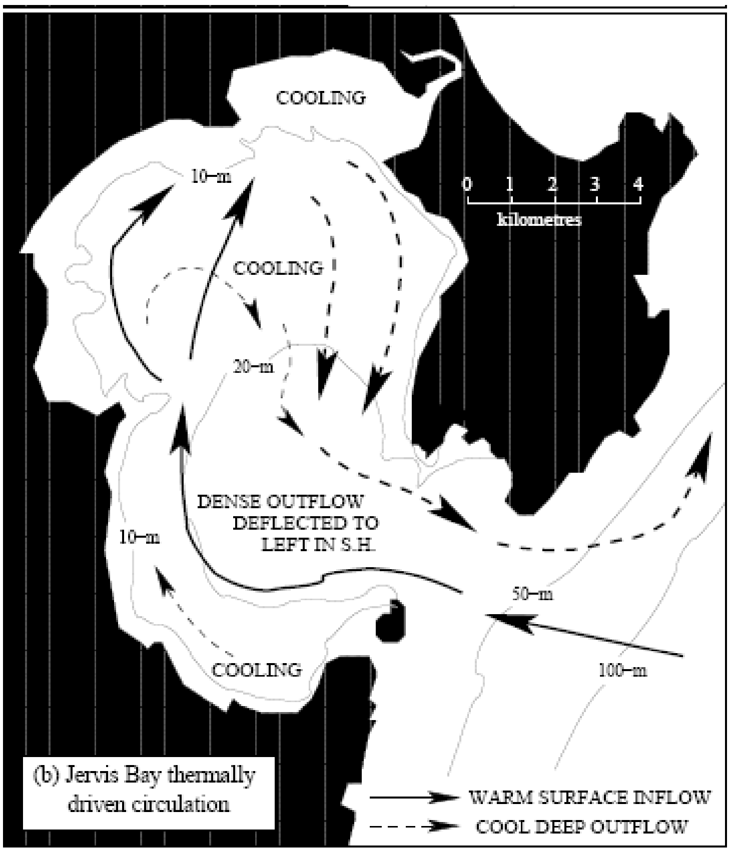

Figure 2-2. Bathymetry of Jervis Bay, from England and Moore (2005)

A key feature of Jervis Bay is the constant transportation of water into and out of the bay due to a circular flow that enters the bay on the southern side and discharges from the bay near the seabed on the northern side (CSIRO 1994, 1994). The water catchment area for Jervis Bay is approximately 400km^2, and is unique insomuch as no major rivers flow into the Bay (Brown, Nudd, and Scarsbrick 1995; West et al. 1985). The fact that no major freshwater estuaries flow into the bay means that hydrological processes are mainly driven by oceanic processes (e.g., current flow trajectories and tidal processes). Currambene Creek is the main source of potential run-off during heavy rainstorms, at which time it can supply the bay with inflows of fresh water at approx 30ppt (Jacobs 1983). This water mass remains on the surface and generally flows out of the bay without substantial mixing in the water column. Overall nutrient inputs from the catchment are small, giving the water a deep blue appearance, which also indicates low levels of nutrients and relatively low plankton levels, similar to that of offshore waters. Although the low levels of runoff potentially indicate low nutrient inputs, and thus lower levels of biological productivity than the NSW estuarine areas that are traditionally used to culture shellfish, the positive characteristics of clear oceanic waters and high, reliable water exchange nonetheless indicate good potential for shellfish production.

Jervis Bay is affected by two different water masses - the East Australia Current (EAC) which moves southwards from the Coral Sea along the outer continental shelf and continental slope region and the Tasman Sea waters that at times move northwards along the inner part of the shelf. Each of these water masses alters ambient water temperature at the mouth of Jervis Bay, and temperatures will, depending on prevailing winds, extend along the shelf or enter the bay (Holloway et al. 1991).

A good understanding of the water movement and mixing patterns in Jervis Bay, as well as temporal and spatial variability of the physical and chemical characteristics of the bay, are important when selecting potential aquaculture species for commercial production. Currents in Jervis Bay are characterized by persistent flows in one direction for long periods of time (e.g., several months), and it is suggested that influences from the continental shelf are responsible for driving the bay circulation (Holloway, Symonds, and Nunes Vaz 1992). Overall the water circulation in Jervis Bay is influenced by four types of currents: thermohaline circulation, tidal processes, eddies, and coastal trapped waves (CTW) formation.

2.2.2 Thermohaline circulation

The water circulation at the Jervis Bay mouth is well understood based on historical research (Holloway et al. 1990; CSIRO 1994). It has been shown that there is a persistent outflow of dense (cold) bay water at the near seabed off Point Perpendicular (north side of the mouth) with a compensating inflow of buoyant (warmer) shelf water near the surface off Bowen Island (south point at the mouth). Flushing times in Jervis Bay vary due to differences in the strength of the currents at the entrance, resulting in different turnover rates depending on the geographical point and climatic conditions within the Bay. However, on average, waters have been calculated to remain in the bay between a broad range of 10 to 74 days, before being flushed into oceanic waters at the mouth (Holloway et al. 1991) These findings were based on estimates of volume fluxes in and out of the bay from measurements of flow velocities. An alternative flushing rate calculation using a tidal prism method was used in this report, which yields a water exchange time scale of approximately 6 days. This additional calculation was undertaken in order to consider effects of the water retention component of calculations in section 3.1, and provides additional scenarios to consider.

Seasonal differences in temperature and salinity are encountered within the bay. In summer the shelf water is generally temperature-stratified while in winter it is more homogeneous. A temperature gradient of almost 5°C has been recorded on occasion within the water column in the deepest areas of the bay (Holloway et al. 1990; Santoso 2005). The warmest water temperature occurs between February and May at around 23°C (Jacobs 1983). The coldest temperatures are reached between August and September, dropping to around 13.6-14°C (Jacobs 1983). Water temperature drops as a result of upwelling processes that bring dense deep water into the bay (Holloway et al. 1991). In addition, the waters in the shallow areas in the northern side of the bay tend to cool more quickly than in the south, consequently sinking close to the seabed and resulting in cold patches around the proposed aquaculture lease areas. In contrast, salinity levels in the bay remain relatively constant and any variation is likely to occur as a short pulse from fresh-water flooding during heavy rainfall periods.

2.2.3 Tidal flows

Tides along the southern coast of NSW are generally weak, as are the local winds. The tides on this part of the coast are semi-diurnal (i.e. two high tides a day), at times with large inequalities when the height of the two high tides within a day are different. Currents associated with tidal motion are very weak with speeds of 0.07m/s at the entrance of the bay and <0.01m/s in the inner northern areas of the bay (Holloway et al. 1989).

Weak tides result in little net horizontal transport of water by the tidal flow. Holloway (1995) predicted that the maximum horizontal displacement that a particle within the water body of Jervis Bay will travel is 700m for a semi-diurnal tidal current of 0.05cm/s. Consequently, tides appear to play a minor role in the transport of water in the bay.

2.2.4 Eddy formation

Most of the EAC turns to the east slightly north of Sydney, transporting the warm water along the Tasman Front towards New Zealand (Holloway 1995). A small proportion of the warm water keeps its flow southwards losing energy and forming eddies, which slowly wander southwards towards Tasmania. When passing close to Jervis Bay, they have the capacity to influence regional water temperature and produce strong currents of 1m/s on the shelf (Holloway 1995). At times cold waters from the Tasman Sea travel north along the inner part of the shelf, reaching Jervis Bay and mixing with water currents entering the bay (Holloway et al. 1991). Consequently, monitoring eddy formation at the mouth of the bay will help towards predicting circulation patterns for the bay.

2.2.5 Coastal trapped waves (CTW)

The shelf waters are well known for their coastally trapped waves (CTW). One of the mechanisms in forcing the circulation in Jervis Bay is the scattering of the CTWs on the adjacent continental shelf (Craig and Holloway 1992). These waves have been observed propagating towards the north along the EAC (Wang and Wang 2003). CTWs are capable of influencing the vertical temperature profile, indicating that these waves are an additional mechanism driving circulation in the bay.

Although the water circulation processes and physical parameters of the overall bay are well understood, a number of small-scale processes, driven by prevailing winds and currents near the continental shelf, may present unusual patchy conditions that could have impacts on some aquaculture species that require or are limited by specific environmental parameters of the area (Santonso 2005; Wang & Symonds, 1999; England & Moore, 2005; Jacobs 1983; Craig & Holloway, 1992). It is worth noting that NSW Integrated Marine Observing System (IMOS at http://imos.org.au/nswimos.html) is currently deploying instrumentation that would assist in monitoring eddy formation and EAC at the mouth of Jervis Bay. In addition to past research and computer models developed for the area, this information will assist in developing accurate estimations of productivity at the proposed aquaculture leases. Additional field trials will also necessary by industry before determinations can be made on the feasibility of different species for culture within the bay.

2.3 Suitability of Jervis Bay for Aquaculture

2.3.1 Past shellfish aquaculture and commercial fisheries in Jervis Bay

The most recent aquaculture enterprise in Jervis Bay was a small experimental trial of blue mussels (*Mytilus galloprovincialis*) using raft-based cultivation systems which began in 1977 and ceased in April 2008. While operating, commercial mussel production varied from 0.5 to 23 tons between 1978 and 2007, with the average being approximately 7.5 tons per annum (I&INSW) from a 60x4m raft in addition to a 1ha spat collection lease based in Twofold Bay. The mussel raft was anchored near Dent Rock and Plantation Point.

In the 1980's, Sydney rock oysters (*Saccostrea glomerata*) were cultivated in Currambene Creek producing ~10 tons/yr (Fuentes et al. 1992). These oyster leases were surrendered in the late 1990's as production was variable and juveniles needed to be sourced from other estuaries or hatcheries.

In addition, there have also been three wild shellfisheries in Jervis Bay including a wild fishery for blue mussels (*Mytilus galloprovincialis*) (Fuentes et al. 1992), scallops (*Pecten fumatus*), and flat oysters (*Ostrea angasi*). All fisheries exhibited considerable annual variability in recruitment. Both flat oysters and scallops were harvested by dredge boats and commercial divers. Scallops were present in large quantities in most areas of Jervis Bay, while flat oyster stocks were primarily concentrated in the eastern side of the bay (Brown, Nudd, and Scarsbrick 1995). Scallop production values in Jervis Bay accounted for 90% of the NSW scallop catch in 1981/82, although catches later declined and the commercial fishery has since been discontinued (Fuentes et al. 1992). Both scallops and flat oysters decreased significantly in abundance until the early 1980s, and a series of research programs for reseeding scallops and flat oysters were undertaken in the late 1980s. These programs included hatchery spat production (Heasman et al. 1998), as well as monitoring of reproductive biology of endemic populations and assessments of the feasibility of reseeding (Fuentes et al. 1992). To date however, none of these species has been cultivated in Jervis Bay.

2.3.2 Physical characteristics of the bay

The proposed lease areas in Jervis Bay are in waters of approximately 10m depth. The water column at these sites appears to be temperature-stratified during the summer periods and homogeneous during the winter periods. Depending on the species and cultivation method, this could suggest a need for different seasonal management strategies, and potentially limited production for certain periods of the year. Table 1 indicates that temperature and salinity ranges are variable for each month as a result of inter-annual variability. For instance, in certain years, water temperatures have been recorded to be around 13.6°C, which is not optimal for specific aquaculture species (Table 2-2).

Table 2-1. Physical characteristics of Jervis Bay that could potentially influence suitability for bivalve culture.

Physical parameters	Characteristics of lease areas in Jervis Bay
Mean Circulation	**General direction:** CSIRO and UNSW determined that in general warm surface currents enter the bay close to the south end of the mouth, following westward along the coast. By the time waters reach the end of the bay, and turn to flow out on the eastern side, cooling occurs and waters leave the bay through down-welling along the north side of the mouth (temperature and salinity driven). Other processes drive the circulation based on tidal currents, eddy formation and coastal trapped waves (Holloway et al. 1989).
	Current speeds: At the mouth, water inflow enters the bay at 0.2m/s (England and Moore 2005) while at the inside of the bay (at lease locations), the speed drops dramatically to 0.5cm/s with a range of 0.3-12cm/s (Holloway et al. 1989)
Winds and Waves	**Direction:** The wind generally blows towards the southwest at the proposed leases locations, with waves and swells following a southward direction at 6-14 second wave periods (McCowan et al, 1987). Average wave height ranges from 1-2m with maximum height recorded at 7m (Brown, Nudd, and Scarsbrick 1995). Wave energy is generally small, as energy entering at the mouth is distributed along the whole bay's circumference.
Tides	Tides are small as per the rest of the NSW coast (i.e., narrow continental shelf and little phase difference between points on the coastline). Jervis Bay experiences full oceanic tidal height change (~2m) with a minimal delay (Brown, Nudd, and Scarsbrick 1995).
Dissolved Oxygen	Values recorded within the Bay are high, though slightly lower (<80%) at the creeks (Brown, Nudd, and Scarsbrick 1995)
pH	Consistent with that of seawater due to high flushing rates (Brown, Nudd, and Scarsbrick 1995)
Nutrients	Two main sources: upwelling offshore currents prevailing oceanic conditions and runoff from surrounding catchment. Potential input from groundwater discharges (Brown, Nudd, and Scarsbrick 1995)
Salinity	High due to high flushing rates. Salinity remains relatively constant (Holloway, Symonds, and Nunes Vaz 1992; CSIRO 1994) Only heavy rain events would bring significant amounts of freshwater into the bay (Holloway 1995).
Temperature	Consistent with adjacent coastal waters but with distinct seasonal trends, and small variations through water column at certain times of year as a result of intrusions of cold nutrient rich waters.
Phytoplankton Biomass and Chlorophyll-a	Incoming Tide: 163.4 ± 38.6 cells/ml Outgoing Tide: 53.2 ±12.9 cells/ml (Cheong 2004) Chl-a: Sept-98 at surface= >3mg/m^3; at 10m=1-2mg/m^3 (Nov-98; Feb-99 & Mar 99 through the water column <1mg/m^3 (Dela-Cruz et al., 2003)
Zooplankton Biomass	Incoming Tide: 1316.4 ± 259.4 organisms/L Outgoing Tide: 444.9 ±87.9 organisms/L (Cheong 2004)
Turbidity Levels	Incoming Tide: 2.2 NTU Outgoing Tide: 2.3 NTU (Cheong 2004)

Table 2-2 Salinity and temperature at surface and 9.5m depth as applicable to the proposed aquaculture lease areas.

N.B. Data extracted for areas in proximity to the proposed leases from the following literature for years 1983; 1989-92(Jacobs 1983; Holloway et al. 1989; Holloway et al. 1990; Holloway, Symonds, and Nunes Vaz 1992; Holloway, Nunes Vaz, and Symonds 1992).

	Surface water temperature	Deep water (9.5m) temperature	Surface salinity	Deep water (9.5m) salinity
Jan	20-23.1	20-22.9	33.8-35.5	34.5-35.5
Feb	21.1-23.1	20.9-22.6	35.4-35.6	35.5-35.6
Mar	19.4-22.1	18.6-20.9	35-36	35-35.4
Apr	17.5-21.4	17.2-21.7	33.8-35.7	34.9-35.8
May	18.1-19.5	18-19.7	33.7-35.1	33.9-35.2
Jun	14-18.2	14-18.4	35-35.1	35.1-35.4
Jul	13.6-15.6	13.6-15.5	34.8-35.5	34.8-35.5
Aug	13.9-16.19	13.9-15.99	35.4-35.6	35.4-35.6
Sept	14.9-16.2	14.88-15.9	35.4-35.5	35.4-35.5
Oct	16.2-18	16.1-17.8	35.2-35.5	35.2-35.5
Nov	17.2-19.8	16.8-18.9	35.4-35.5	35.3-35.5
Dec	17-21	16.9-21	31.7-35.2	35-35.7

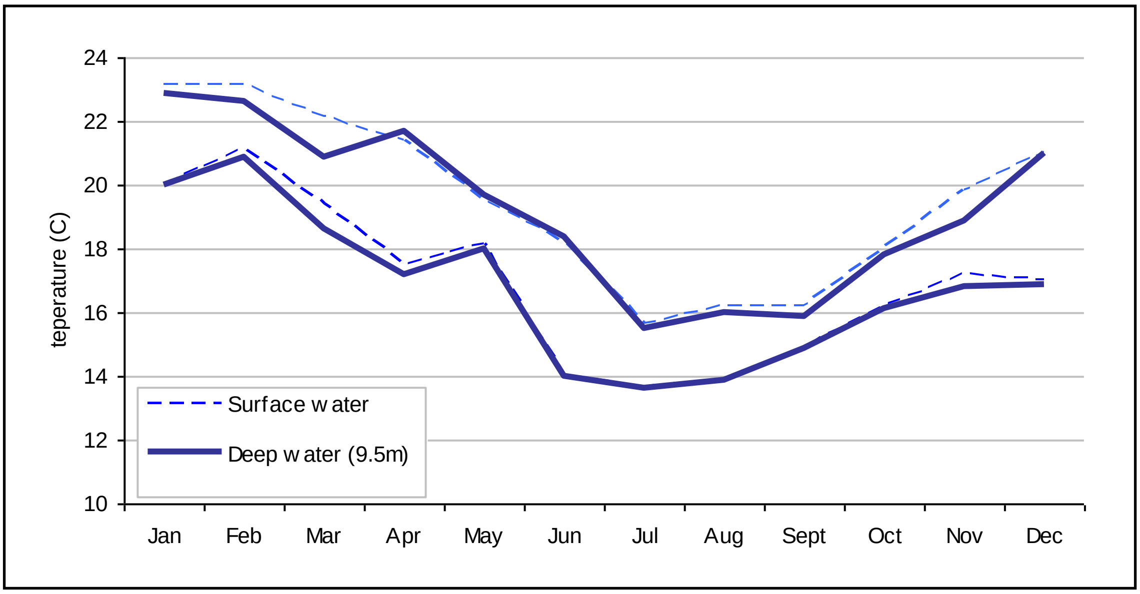

Figure 2-3 Seasonal temperature measurements at proposed lease areas

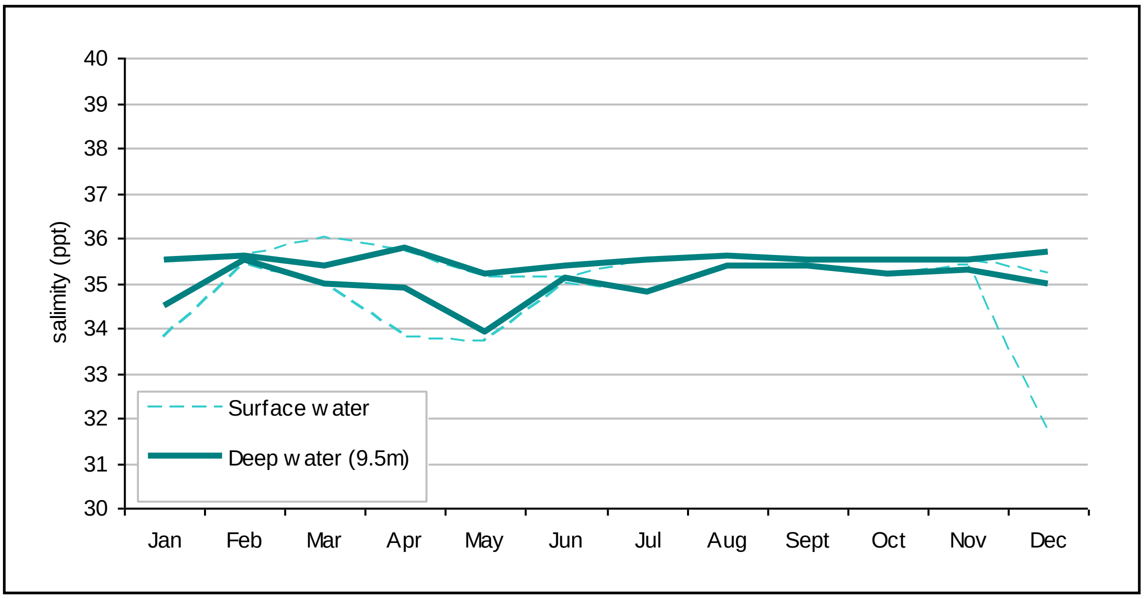

Figure 2-4 Seasonal salinity measurements at proposed lease areas

Minimum information has been found with regard to primary productivity of the bay. It appears that chlorophyll-a levels (Dela-Cruz, Middleton, and Suthers 2003) are typical of temperate NSW oyster producing estuaries, and therefore there is potential for aquaculture production. Since these levels are not extremely high, there is a need to cultivate species within appropriate stocking densities based on the capacity of the lease, in order to minimize local depletion of food sources in the area.

Although the proposed lease area might be exposed to northeasterly winds at times, the area appears to be relatively sheltered which would result in reduced stock loss from wind and wave action. Consequently, the proposed areas for aquaculture appear to be good for establishing infrastructure without the need for offshore anchoring technology. Based on the data compiled, it also appears the bay has suitable rapid water exchange and reasonable primary productivity – all of which are factors indicating good potential for extensive aquaculture. As such, Jervis Bay is one of only three marine embayments on the NSW coast that are likely suitable for near-shore extensive aquaculture, with the other locations being Twofold Bay, which already has extensive mussel aquaculture, and Port Stephens, which has an established edible oyster industry and areas approved for pearl oyster production.

2.3.3 Habitat characteristics and sediment in proximity to lease areas

The NSW Comprehensive Coastal Assessment (West et al 2006) provides detailed maps of the diverse range of habitats which exist within the Jervis Bay Marine Park, including seagrass beds, mangroves, sandy beaches, intertidal rocky shores, subtidal rocky reefs, soft substrate habitats, and drift algae communities. In addition, CSIRO completed baseline studies of Jervis Bay in 1994 and identified a diversity of soft sediment habitat types in and around the proposed aquaculture precincts (Figure 6). The benthic environment in the area of the proposed leases is primarily fine to medium grained sand and small cobble, with distinct areas of bioturbated sand, bivalve clumps, wave rippled sand and drift algae. Diver transects at the previous lease site indicate that there are sparse patches of *Halophila australis* dispersed through habitat identified as "bioturbated sand" (Plate 1). Some *Posidonia* *australis* is located at the southern end of precinct 1, while rocky reef habitat is located at the northern end. It is anticipate that any sedimentation effects from Precinct 1 would flow with the prevailing N/NE flow rather than southwards.

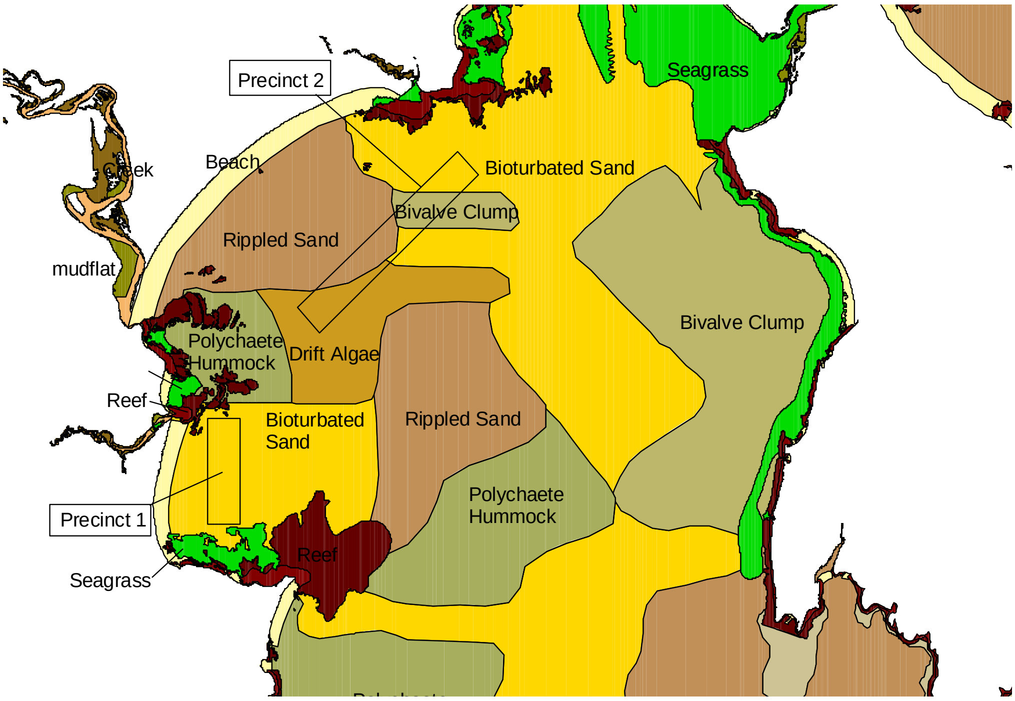

Figure 2-5 Habitat/sediment in Jervis Bay in and around proposed precincts (data from CSIRO 1994)

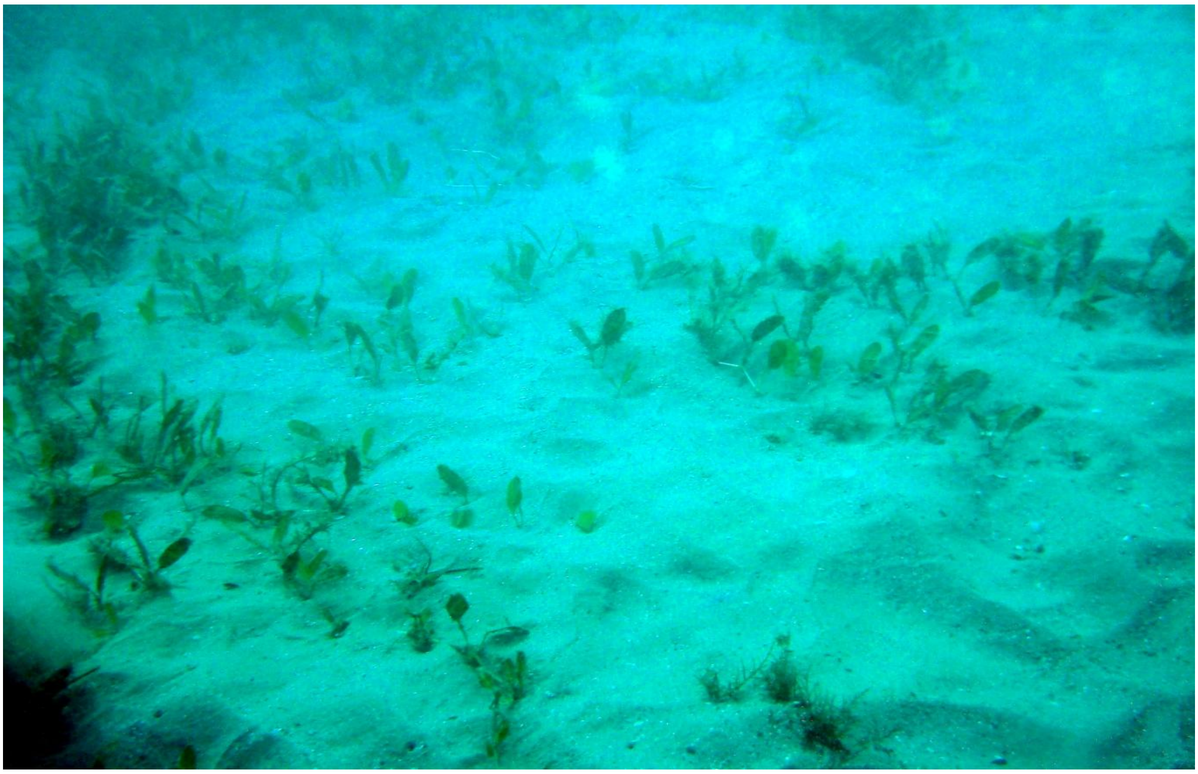

Plate 1. Halophila australis located at previous mussel pilot site within precinct 1 habitat "bioturbatred sand" (photo: P.Winberg).

2.4 Long-line Systems for Shellfish Aquaculture in Jervis Bay

Long-line cultivation consists of anchored lines to the bottom from which cultivation infrastructure is suspended within the water column (e.g., lantern nets, baskets, ropes). These cultivation systems, as opposed to rafts or surface installations, are preferred and suggested in the Draft AIDP for Jervis Bay for the following reasons:

- Less obstructive for recreational boating
- Result in the least visual obstruction
- Present low impact on the substrate based on the anchorage set-up (i.e. low sediment surface anchorage points)
- Minimise predation of cultured species by sedentary/benthic marine organisms
- Optimal infrastructure for dealing with rough surface waters or strong currents
- Capacity to move stock within the water column in order to: 1) maximize shellfish production based on food levels through the water column; 2) minimise fouling and 3) avoid fresh layers after rainfall events
- Easier to clean and maintain

Long-line systems are the predominant culture method for shellfish cultivation in Australia, in particular for mussels, but can also be used for oysters, scallops or other species. Depending on the species cultivated, the following configurations are possible for set-up of long-line systems:

Horizontal systems consists of a long rope (long-line), anchored at either end to prevent the long-lines from shifting in heavy seas and strong currents. The central section of the rope is held by floats which can be attached at intervals at the surface (or in suspension at a certain depth) to maintain buoyancy. Several technological advances have allowed for set-up of ropes and cultivation infrastructure fully submerged, although at the surface some floats are still necessary and would also mark the boundaries of the lease.

Long-line cultivation can also be set up in a vertical array in which individual lines are secured to the seafloor and supported at the surface or subsurface by buoys (e.g., a single-dropper system). Cultivation infrastructure is then attached to these lines, although these systems are in general considered to be inefficient, and it is unclear whether any environmental benefits are achieved by this configuration.

2.5 Potential Candidate Species for Jervis Bay Long-Line Cultivation Systems

The list of species in Table 2-3, which is not exhaustive, represents a compilation of potential bivalve mollusc species that meet the criteria of the Jervis Bay Marine Park zoning for extensive aquaculture (e.g., endemic species that can be cultivated in a long-line system). In this report, there is no consideration of other species such as clams, abalone, sea urchins, or sea cucumbers which could also be economically viable, particularly in an Integrated Multi-Trophic aquaculture system (i.e., sea cucumbers cultured under mussel lines and scallop lantern nets (Zhou et al. 2006). However, the scope of this list should not preclude further investigation of other species which may be of interest, including other invertebrate species or seaweeds. Business plans which account for production of multiple species at a given site can generally be advantageous, as this type of culture can potentially improve profitability and diversify financial risks (Bunting 2008; Whitmarsh, Cook, and Black 2006).

All of the farming techniques for species listed in Table 2-3 require reliable hatchery-based spat sources, as few of these species are currently grown efficiently using wild spat collection. Options for translocation of wild spat are limited in light of potential risks and translocation protocols are available from I&INSW, as discussed further in Section 4. Recruitment in Jervis Bay is variable for all of the species considered, so a key factor in developing aquaculture in Jervis Bay will be the availability of spat, which in some cases, is currently limited by the lack of a multi-species commercial hatchery in NSW. Extensive research has been conducted at the Port Stephens I&INSW hatchery and other Australian hatcheries demonstrating that all species under consideration can be successfully cultured, but a hatchery in NSW is preferable for reliable supply to aquaculture operations in this region. The Jervis Bay area may also be ideally suited for nursery facilities that could also extend spat production at a hatchery into commercial seed stock production.

Based on the temperature, salinity, and hydrodynamics in the bay, all of the species shown in Table 3 are potentially feasible for cultivation in Jervis Bay. Akoya pearl oyster is the only species that is at the edge of its geographical distribution and consequently, some of the low temperatures recorded will limit growth in winter months or may require seasonal operations. Of interest however, is that growers of Akoya Pearls believe that the finishing quality of pearl oyster in the cooler Jervis Bay waters may supply a superior product (industry comment). As suggested in section 2.4.1, temperature and salinity levels are generally stable in Jervis Bay, but freshwater flushing events and localized temperature variation suggest that further experimental trials and temperature monitoring at the exact lease sites is needed.

Table 2-3 Potential aquaculture species in Jervis Bay

Species	Criteria for cultivation	Spat source	Criteria met in Jervis Bay
Blue mussel (*Mytilus galloprovincialis*)	-Wide environmental tolerance -Cultivation depth (2-15m) -Range of tolerance to salinity levels, generally 15-32ppm (Nell and Gibbs 1986) -Water movement (currents ~5m/s) -Good flushing of water -Sandy bottom that can maximize breakdown and dispersion of biodeposition, minimise predators	-Consistent wild spat supply. Wild spat may be sourced from Twofold Bay. Spat also available from commercial hatcheries in Victoria or Tasmania (preferable)	Yes, provided spat can be obtained from hatchery sources in ways that meet appropriate translocation protocols.
Scallops (*Pecten fumatus*)	-Large numbers of existing scallop beds, although mainly on the eastern side of the Bay -Low tolerance to changes in salinity, temperature, deoxygenation, and siltation	-No known commercial hatchery source, though they have been successful on an experimental basis at the Port Stephens hatchery. Wild spat collection costly and time consuming	No source of spat available, thus limiting feasibility. Other biophysical factors may also be limiting based on prior trials.
Akoya pearl oyster (*Pinctada imbricata*)	-Cultivation depth (2-10m) -Prefer warmer water temperature. -Winter season (~14°C), trials will need to be conducted to determine viability during those months	-Spat may be available, will need to be sourced from a hatchery	Yes, provided spat can be obtained from hatchery sources in ways that meet with appropriate translocation protocols.
Sydney rock oyster (*Saccostrea glomerata*)	-Cultivation depth (2-5m) -Optimal salinity 25-35 -Optimal temperature 18-30C -Tolerate wide range of temperature and salinity -Frequent flushing of water	-Consistent wild spat supply. Spat will need to be sourced from other NSW estuaries or is widely available from hatcheries	Yes, but less kely to be most productive species in Jervis Bay, due to a range of limiting biophysical factors.
Angasi or Flat oyster (*Ostrea angasi*)	- Temperature and salinity sensitive - Optimal temperature 10-18C, will tolerate higher temperatures	-Spat supply will need to be sourced from a hatchery, appears to be consistently available	Yes, hatchery-sourced spat appears to be available from sources that meet appropriate translocation protocols.

3 KEY ENVIRONMENTAL CONSIDERATIONS AND MITIGATION

The environmental impact of marine aquaculture is an important issue for the future development of the industry, and it is important that the environmental effects are managed in a manner that is acceptable to the broader community. Environmental risk assessment (ERA) is used widely to address the risks associated with industrial processes, and may serve as a useful tool to support an informed precautionary approach for aquaculture development. Uncertainty is also particularly important issue to consider, as some of the impacts of shellfish production (such as deposition of organic matter) can be measured with reasonable confidence limits, while impacts on the wider coastal environment, and in particular on wild fish populations, require further research.

Debates regarding shellfish aquaculture's potential impacts tend to center around two concerns: the issue of carrying capacity, sustainable scale or density of cultivation, in a given area and the possible direct environmental impacts on habitat as a result of shellfish production. Both concerns are addressed in this section, first ecological carrying capacity, and then a range of potential environmental impacts. Finally, a risk assessment is provided considering the potential environmental impacts in the context of establishing shellfish aquaculture in the proposed precincts in Jervis Bay.

3.1 Ecological Carrying Capacity

As an extensive, no feed-input aquaculture technology, the ecological impact of bivalve aquaculture is essentially a redistribution of nutrients. Nutrients, in the form of phytoplankton and zooplankton are stripped from the water and organic wastes are returned to the water as faeces or pseudofaeces. Therefore bivalve culture is integrally linked to its environment through water circulation and primary production. For sustainable cultivation, the scale and design needs to work within the limitations of the ecological carrying capacity of the area, both for viability of the farm and cumulative impacts on the environment. Consequently factors such as stocking density, cultivation scale, management practices, local environmental sensitivity and the resilience of the local habitats are considered fundamental to assessments of aquaculture impacts.

Although bivalve culture is considered to be a low impact form of aquaculture worldwide (Crawford, Macleod, and Mitchell 2003; McKinnon et al. 2003; Lasiak, Underwood, and Hoskin 2006), there is particular concern on the long-line culture of certain bivalves such as mussels which are believed to have relatively high potential for local and bay-wide impacts (ICES 2004). This rearing technique could involve the deployment of densely packed mussel cohorts throughout much of the water column, resulting in relatively high stocking densities per unit area and volume compared with other bivalve species, particularly if the waterbody where cultivation exits is a good spat collecting area. Large number of bivalves could contribute to significant localised particle depletion. This will only become a concern when large populations of filter feeders remove food particles faster than the tidal exchange provides them, resulting in a significant reduction in the particulate food supply for extended periods, thus depressing natural populations of secondary producers (Cranford et al. 2006).

Consequently overall concerns have been raised about the possible effects that extensive shellfish culture operations could have on aquatic ecosystems, in particular on the benthos, and the related risks to the ecological functioning and sustainability of the lease areas. As a result, an environmental index has been calculated to assess the potential impact of bivalve culture based on the physical characteristics of the cultivation area and the filtration capacity of the cultured species. This index has been previously referred to as Clearance Efficiency Index (Gibbs 2007) or Phytoplankton Depletion Index (WWF 2010). The index is a measure of the time that water remains in an area compared to the time that it takes for a group of molluscs to filter that water. With this index, bivalve filtration rates are compared to the physical processes that contribute to food renewal in Jervis Bay. However, the actual quantities of food in the water column or its internal production rate are not considered in the calculation of this index here. If the latter information were determined in a baseline study, the parameters used in this calculation could be tailored to the Jervis Bay site and additional indices proposed by Gibbs (2007) could also be used towards calculating the ecological carrying capacity of the area.

The Clearance Efficiency Index (CEI) compares the time it takes for a body of water (i.e., within the lease area) to be flushed (Residence Time, RT) versus the time it takes a population of bivalves to clear that volume of water based on their filtration rates (Clearance Time, CT).
RT used in this section were obtained from two sources:

1) Holloway et al. (1991) estimated monthly flushing times for Jervis Bay based on volume fluxes in and out of the bay from measurements of flow velocities. These calculations indicated that the flushing times were quite variable depending on the month, and were between 10 and 74 days with an average RT1 of 19±5 days. Although this estimate is for the whole bay, it is assumed here that it is representative of the proposed lease precincts.
2) The RT for the lease areas in Jervis Bay was calculated based on literature data of the tidal range, lease areas and depth (Table 3-1 & Table *3-2*). Calculations for the RT were estimated based on the tidal prism of the bay:
   RT2 = -1 x P / ln (Vl / Vt)
   Where, tidal periodicity (P) is the length of the tidal cycle (e.g., ~0.5 days for semidiurnal tides); Vl is the lease volume at low tide and Vt is the total volume of the corresponding water body at high tide (liters) (WWF 2010). RT2 values are shown in Table 3-2.

Table 3-1 Water exchange for Jervis Bay and size of aquaculture Precinct areas

	Area (Ha)	Average depth (m)	Tidal range (m)
Precinct 1	50	10	0.7
Precinct 2	100	10	0.7

	Total volume (m3)	Mouth area (m2)	Current at mouth (m/s)
Jervis Bay	1,890,000,000	140,000	0.2
			(England & Moore, 2005)

The CT was calculated based on bivalve clearance rates values for adult size-class recorded in the literature for the different species of interest in Jervis Bay (Tables 3-3 and 3-4). Two ranges of clearance rate values have been used: high and low clearance rates. There is potential to improve this variable input by using clearance rates equations dependent on an in-situ water quality parameter (e.g., POM, Chl-a, Temperature).

Low values of the CEI (<1) indicate that the culture does not reach the maximum ecological capacity of the area whereas high values (>1) indicate that the lease area is being flushed at a slower rate than the corresponding cultured bivalve filtration rate. Within the low values, the culture system needs to be initially validated for potential impact on the benthos (e.g., concomitant benthic sampling, seabed video transects) so that bivalve cultivation systems could be set and maintained at a certain index level with no need for further impact benthic monitoring programs to be undertaken. A cultivation system maintained within the low levels of the CEI ensures that the cultured bivalves are not regulating (i.e. top-down control process) the in-situ phytoplankton dynamics and the normal aquatic process are still naturally driven.

3.1.1 Results: Ecological Carrying Capacity

The RT_2 values were 6.7 days for the overall bay calculation, compared to 19 days for RT_1. A large difference like this is to be expected since RT_2 is based on tidal forcings and data from Ulladulla, a smaller bay outside but close to Jervis Bay, while the signature of the tidal processes on the overall water circulation of Jervis Bay is small. If tidal processes are not significant drivers of the circulation of the Bay, the RT_2 values would be expected to be larger, not smaller, than the RT_1. This calculation for RT_2 will be still considered in this section as the RT_2 equation has been used before (WWF 2010; Gibbs 2007) and could be more accurately determined if data for the specific precinct locations is collected in future baseline studies. Consequently, both values were considered in the calculation of the CEI, although RT_1 should be regarded as the more conservative value since the retention period is longer. Table 6 and 7 show the optimum density values calculated for each of the potential cultured species based on their clearance rates so that the ecological carrying capacity of the lease is not exceed (i.e. CEI<1). It is also worth pointing out at this stage that this index assumes that none of the cleared water re-enters the system. Residence time values calculated in this way will therefore under-estimate the real times, particularly in upstream locations.

The stocking densities used in the calculation of the CEI were based on typical densities for long-line systems off which bivalves are cultivated in floating oyster bags and trays, pearl oyster and scallop lantern nets, and mussel droppers. Other cultivation methods are also appropriate for long-line systems. The proposed leases areas of 150ha could hold between 810 and 2025 tons of Sydney rock oysters, 810 and 2106 tons of flat oysters, 12 and 36 tons of pearl oysters, 240 and 660 tons of mussels or 48 and 135 tons of scallops based on RT_1 and RT_2, respectively (

Table 3-3 and Table 3-4). These values are reflective of low density cultivations, in particular if Holloway's RT values are used. Overall, stocking densities have to be reduced by 70% in order to reach a CEI of approximately less than 1 for the high clearance rates (i.e. using the upper limit estimate). Since most of these species will be brought into the bay from external sources, controlling the stocking densities at the Jervis Bay leases should be manageable. In addition, approximately 1 to 2 juvenile lines should be factored into the calculations for each 10 grow-out lines, depending on the species. Juvenile bivalves will have less impact on the environment than harvest size animals, therefore, the calculations indicate more sustainable levels overall.

The calculations here provide estimates of a sustainable scale of shellfish farming at the precincts identified for different species, from the perspective of minimising impacts on the planktonic and benthic habitats. It also provides information from which to calculate the required area of surface infrastructure for different forms of cultivation, scale of impacts on visual amenity, estimating the most financially viable form of aquaculture (cottage industry, medium enterprise with seabased processing or opportunity to invest in shore and land-based infrastructure) and the potential for local employment.

It is worth noting that the overall values used for this calculation are assumed to be spatially homogeneous within the precincts under consideration. Densities, for instance, are likely to be highly variable within a growing area. If ocean mixing within an area of the bay is weak, then food resources can be severely depleted locally within a small area surrounding a lease. In addition, waters close to the mouth/opening of the bay will have shorter flushing times than upstream, where the leases will be located. The calculation of the RT here does not address this point, however further data could be sourced from some of the Jervis Bay models developed by the UNSW (England and Moore 2005; Santoso 2005, Wang, 2003).

Table 3-2 Clearance Efficiency Index (CEI) calculations for proposed Jervis Bay leases

Clearance Efficiency Index (CEI) calculations for proposed leases in Jervis Bay using RT1 and RT2 values. High and low clearance rates (CR) published in the literature for suggested cultured species as per in Table 6 and 7. If CEI<1 means that the volume of water filtered by the population of bivalves is less than the volume exchanged by tidal processes, therefore not exceeding the ecological carrying capacity of the area.

CEI		Sydney Rocks	Flat Oysters	Pearl Oysters	Mussels	Scallops
	RT1- densities as per Table 6	1.08	1.09	0.94	1.02	1.02
(based on HIGH CR)	**RT2- densities as per Table 7**	0.95	1.00	1.00	0.99	1.01
	RT1- densities as per Table 6	0.65	0.27	0.11	0.32	0.73
(based on LOW CR)	**RT2- densities as per Table 7**	0.58	0.25	0.11	0.31	0.72

Table 3-3 Optimal stocking densities required for sustainable CEIs in Jervis Bay leases based on residence time (RT1) from Holloway (1991)

N.B. based on Residence Time from Holloway et al, 1991 (RT1), some of the references used for clearance rates of bivalves are for closely related bivalve species.

Cultured Species	Densities Numbers /Ha	Average weight (g) harvest size	Production (based on densities) Kg for Precint-1 (50Ha)	Production (based on densities) Kg for Precint-2 (100Ha)	Low-CR (L/hr)	High-CR (L/hr)	References
Sydney rock oyster (*Saccostrea glomerata*)	108,000	50	*270,000*	*540,000*	1.33	2.19	(Bayne 1999)
Flat Oyster (*Ostrea angasi*)	60,000	90	*270,000*	*540,000*	1	4	(Haure et al. 1998)
Pearl Oyster (*Pinctada imbricata*)	2,000	40	*4,000*	*8,000*	11.75	103.52	(O'connor, Lawler, and Heasman 2003; Pouvreau, Bodoy, and Buestel 2000)
Blue mussels (*Mytilus edilus, M. galloprovinciallis*)	53,280	30	*79,920*	*159,840*	1.3	4.20	(Campbell and Newell 1998; Pascoe, Parry, and Hawkins 2009; Strohmeier, Strand, and Cranford 2009; Okumus, Bascinar, and Ozkan 2002)
Scallops (*Pecten fumatus*)	6,400	50	*16,000*	*32,000*	25	35	(Li, Veilleux, and Wikfors 2009; Strohmeier, Strand, and Cranford 2009)

While the CEI here used is a far simpler method for assessing the capacity of the lease areas than numerical/computational models, it still requires a significant amount of further physical and biological information in order to estimate it properly. Consequently, more information on the circulation, currents and tidal processes in the bay, in addition, to specific clearance rates of bivalves based on the surrounding water quality of the lease/bay will significantly increased the robustness of the index calculation.

Table 3-4 Optimal stocking densities for sustainable CEIs in Jervis Bay leases based on residence time-from tidal prism calculation (RT_2)

N.B. Some of the references used for clearance rates of species are from closely related bivalve species.

Cultured Species	Densities Numbers /Ha	Average weight (g) harvest size	Production (based on densities) Kg for Precint-1 (50Ha)	Production (based on densities) Kg for Precint-2 (100Ha)	Low-CR (L/hr)	High-CR (L/hr)	References
Sydney rock oyster (*Saccostrea glomerata*)	270,000	50	*675,000*	*1,350,000*	1.33	2.19	(Bayne 1999)
Flat Oyster (*Ostrea angasi*)	156,000	90	*702,000*	*1,404,000*	1	4	(Haure et al. 1998)
Pearl Oyster (*Pinctada imbricata*)	*6,000*	40	*12,000*	*24,000*	11.75	103.52	(O'connor, Lawler, and Heasman 2003; Pouvreau, Bodoy, and Buestel 2000)
Blue mussels (*Mytilus edilus, M. galloprovincialis*)	*146,600*	30	*219,900*	*439,800*	1.3	4.20	(Campbell and Newell 1998; Pascoe, Parry, and Hawkins 2009; Strohmeier, Strand, and Cranford 2009; Okumus, Bascinar, and Ozkan 2002)
Scallops (*Pecten fumatus*)	*18,000*	50	*45,000*	*90,000*	25	35	(Li, Veilleux, and Wikfors 2009; Strohmeier, Strand, and Cranford 2009)

In this section the ecological carrying capacity of the proposed leases in Jervis Bay is estimated based on the information available as part of this desktop study. These studies indicated the overall capacity of the precincts to ensure that aquaculture would not impact on the environment. Consequently, before beginning any commercial activity, it is prudent to conduct small-scale trials for at least 12 months on the intended site. This will give an indication of its overall suitability and with additional information, in particular in regards to water quality, would allow for improvement of the calculated capacity of the precincts to ensure that aquaculture would not impact on the environment.

3.1.2 *Recommendations: Ecological Carrying Capacity*

Hydrodynamic and water quality conditions indicate potential to support a wide range of species and mariculture activities in Jervis Bay. However, the amount and types of shellfish that can be supported within a given area, without adversely affecting the environment or farm productivity, depends largely on the predictive value of measurements employed to accurately determine carrying capacities. Consequently specific calculations of carrying capacity are needed for planning the set-up of aquaculture enterprise

There is a need to collect further baseline data prior to setting up cultivation in Jervis Bay, as data on primary productivity will aid in accurately determining carrying capacity as well as potential productivity of the lease sites, which will also be important for economic evaluations of profitability.

3.2 Other Environmental Impacts

3.2.1 *Benthic Impacts*

Filter feeding results in the packaging of fine suspended particles into large faeces and pseudofaeces that settle on the seabed. The accumulation of faeces and pseudofaeces on the sediment underneath the cultivation could, if not adequately controlled, result in adverse impacts, thus resulting in modification of the sedimentary habitat and the benthic community structure (e.g., typical shift from suspension feeders to deposit feeding species or scavenging gastropods). Many studies, including comprehensive reviews (Cranford 2006; Crawford, Macleod, and Mitchell 2003; Kaiser et al. 1998; Kaiser, Burnell, and Costello 1998) demonstrate a variety of impacts on the benthic marine environment. Some studies indicated significant impacts in cases of over-stocking, such as the presence of extensive bacterial mats and changes in benthic community composition underneath the farms (Hartstein and Rowden 2004; Ysebaert, Hart, and Herman 2009; Forrest and Creese 2006). Benthic deposition can change the chemical composition of the sediment, thus altering nutrient fluxes between the sediment and the water column. It is well known that areas with excessive biodeposition result in anoxic sediments (Kaiser et al. 1998). Such conditions have the potential to affect benthic species, including seagrasses, which is why the substrate under aquaculture leases needs to be considered. In contrast, other studies find minimal effects (Crawford, Macleod, and Mitchell 2003; McKinnon et al. 2003; Lasiak, Underwood, and Hoskin 2006). In areas like Jervis Bay and Two Fold Bay with good flushing rates, the impacts are anticipated to be small.

Further, benthic impacts can also result from accumulation of waste material (e.g., shells, decomposing mollusc species and accumulation of removed bio-fouling species) under the farm or from generating sediment plumes as a result of cleaning/ maintaining infrastructure. However, the severity of physico-chemical and biological impacts on the benthos will depend on the nature of the waste (inorganic or organic) and the extent of accumulation. This will, in turn, depend on water depth, water currents and movements under the farm (Gavine and Mc Kinnon 2002). As with pelagic impacts, farm management practices play a role in determining impacts on the sediments. Current testing in Twofold Bay indicates little or no impact from mussel farming activity (IINSW comment).

3.2.2 Translocation of Species and Pest Management

Biosecurity protocols can prevent inadvertent aquatic pathogen and pest introductions. A sound biosecurity program for shellfish aquaculture would incorporate

a) clear indications of risk parameters prior to farm set-up,

b) monitoring,

c) strict adherence to translocation protocols in order to prevent accidental introductions.

The risk of introducing foreign pests or pathogens is much greater with translocation of wild spat collection than with hatchery produced seed. Formerly, mussel seed was collected in Twofold Bay and moved to Jervis Bay, though in future, this type of translocation from Twofold Bay may be inadvisable, as Eden is a primary port of call for international vessels. A source of hatchery spat is preferable from both a biological and production standpoint. Draft translocation protocols are available from I&INSW and would be applicable for any translocation of shellfish spat from out-of-state. Sydney Rock oyster spat and pearl oyster spat are generally available in NSW, but hatchery produced spat of other species is not always readily available at all times, thus translocation protocols would apply to any spat/seed arriving from commercial hatcheries outside of NSW.

3.2.3 Navigation, Recreational, Visual/Scenic, Noise and Waste Disposal

A number of other factors addressed in the Twofold Bay EIS will also be relevant to Jervis Bay. Some of these issues are addressed in Section 5 and the draft AIDP has already considered the identified precincts in relation to stakeholder activities. Further development of management for visual/noise considerations and waste disposal options needs to be undertaken, however none of the impacts described are likely to differ significantly and may be improved though new technology in relation to Twofold Bay. An independent visual/scenic assessment of the impacts of infrastructure, and finally, potential noise considerations from construction, operation or boat usage at an aquaculture facility need to be considered. Best practices can be developed for waste disposal of byproducts of aquaculture processing, including shells, tissue and incidental marine fouling. Further, the mandated use of long-line systems with buoys of uniform shape and color can minimize aesthetic impacts, while submerged longline systems would also facilitate navigation over the leases. Any specific issues in regards to implementing best practices or mitigating potential conflicts would need further considerations within the EIS.

3.2.4 Special Considerations for Operations within a Marine Park

The Jervis Bay Marine Park was established in 1998 by the NSW Government and zoning established in 2002. The waters within the Jervis Bay Park are conserved and managed under the Marine Parks Act 1997. Sanctuary zones protect the marine biodiversity while habitat protection zones also allow for recreational and commercial activities. Extensive aquaculture is permitted in no more than 2% (e.g., 440Ha) of the total area of the Marine Park. Well within that limit, the JBAIDP has identified precincts within the habitat protection zones where it may be most suitable to apply for extensive aquaculture lease areas. Cultivation of exclusively local species would be permitted under Marine Park regulations.

Special consideration is required to site shellfish installations within a marine protected area, as shellfish installations may act as an artificial reef around which fish and other invertebrates congregate, thus representing a fish attractant device (FAD). In general, shellfish farms are viewed positively by fishermen as providing additional habitat for fish and invertebrates. In the case of Jervis Bay Marine Park, the location of sanctuary zones in proximity to shellfish installations carries the risk of potentially luring fish out of protected zones into areas of higher fishing pressure. Given that recreational fishing is currently allowed in proximity to the proposed zoning for shellfish installations, the overall biological effects of this situation on protected sanctuary zones is not known. Overall, the consensus in the literature is that shellfish installations may providing new (artificial) habitat, thus supporting increased fish densities (Dempster et al. 2004; Powers et al. 2007; Tallman and Forrester 2007). Should fish migrate from protected areas towards unprotected aquaculture sites, such a migration could reduce overall habitat competition within sanctuary zones, thus allowing for increased recruitment and survival of remaining stocks within the protected areas while also supporting new populations around the shellfish farms (Connelly and Colwell 2005; Costa-Pierce and Bridger). However the scales of movement of local reef fish species should be considered in Jervis Bay, as much of the literature on FADs and aquaculture focuses on pelagic fish congregations around large fed-finfish farms, and thus provides little evidence in support of the potential FAD effects of shellfish farms in nearshore areas (Dealteris, Kilpatrick, and Rheault 2004; Erbland and Ozbay 2008; McKindsey et al. 2006; Powers et al. 2007). In Western Australia, pink snapper have been observed to congregate around longlines during spawning season where they consume large quantities of mussels (e.g., in 2001, it was estimated that snapper consumed 40 tonnes of mussels directly from shellfish installations in Cockburn Sound; WAMPA 2000). In Western Australia, rays were also observed to congregate around farms in order to feed off shellfish which fall off the longlines. Considerable literature supports that congregations of fish feeding that directly from the farms will also attract larger predatory fish, who may not feed directly on the mussels, but with evident recreational fishing appeal, as well as attracting seals, cetaceans and seabirds, thus also rendering tourism appeal for wildlife viewing. NSW Marine Parks has specific policies in place to ensure that proposals for artificial reefs and FADs in marine parks are consistent with the objects of the Marine Parks Act 1997, and to provide guidance to proponents of artificial reefs or FADs. Although aquaculture is not being installed with the direct intent of acting as an FAD, the relevance of Marine Parks policies on FADs should be determined for proposed aquaculture installations.

3.2.5 Infrastructure interaction with other species

Some reports (Lloyd 2003) suggest that there is a possibility for marine mammal and sea turtle entanglement, or potential for disruption of migratory routes for marine birds and mammals based on aquaculture installations. Most reported concerns about marine mammals and aquaculture relate to fish farms and not specifically shellfish installations (Kemper et al. 2006; Wursig and Gailey 2002). Certainly, the use of longline structures presents a remote possibility that marine mammals may become entangled in culture infrastructure, however, there appears to be only one documented case in the scientific literature of marine mammal entanglement in shellfish infrastructure. In this case it was related to a specific type of mussel farming spat collection line (see Lloyd, 2003). A full discussion of other types of potential interactions between marine mammals and birds (both positive and negative) is given by McKindsey 2006 and Würsig and Gailey (2002).

Considering the extent of shellfish farming globally, there is little evidence that shellfish aquaculture installations pose much direct risks to marine mammals, turtles or seabirds through either entanglement or, in the case of cetaceans, impaired navigation.

3.2.6 *Recommendations: Environmental Considerations*

The purpose of Environmental Impact Statements is to evaluate how environmental stressors may alter the environment, to determine which components of that environment are adversely affected, and to estimate the magnitude of the effects. Frequently it is not clear which environmental component will be affected by the stressor, what type of change will occur and what the exposure will be. Consequently, a number of decisions must be made about the spatial and temporal extent of the impact, the exposure of it (magnitude, duration), and any mitigating factors required after assessment.

Effects can be minimized by using appropriate culture techniques, including culturing appropriate densities of the farmed species, and by implementing operational practices best practices. Programs can be designed to assess and compare the environmental conditions from areas of farming activity, with control areas sharing similar characteristics at some distance from the farm site. When information is available prior to the potential impact, the design is often referred to as a Before–After Control-Impact (BACI) design. As the proposed precincts in Jervis Bay are new, it is urgent that baseline studies are undertaken to provide for BACI design which is the most powerful design for monitoring.

Benthic environmental programs in Australia are generally required for intensive aquaculture (e.g., finfish production), but are only required for extensive aquaculture in some jurisdictions. In Tasmania, shellfish culture license holders are not required to undertake on-going environmental monitoring programs, as long as they annually report the numbers and biomass of shellfish held in the lease area. In NSW however, monitoring programs are required. The most common parameters used in these monitoring programs are: levels (quantity and diversity) of benthic fauna, levels of the organic carbon or organic matter content in the sediment, sediment grain size, redox levels and nutrients (e.g., nitrogen, phosphorus). Samples are generally taken using cores or sediment grabs. Although in the latest studies, underwater video has been frequently used to quantify the impact of the cultivation process as it is a more straight forward methodology and covers a wider spatial scale.

The most frequently used parameters in benthic environmental monitoring are: benthic macrofauna sampling, organic enrichment and sediment particle size. Of the latter, particle size seems to be the most efficient parameter to demonstrate an impact on the benthos. Accumulation of biodeposits or organic matter will result in a change of particle size composition under the farm. Organic enrichment levels and, quantification and biodiversity of benthic organisms have been found to vary seasonally in certain cases. Consequently, there is a need to have substantial temporal and spatial baseline data before monitoring a potential impact as results might reflect natural variation rather than an impact. Sediment analysis is preferable to benthic fauna as an indicator of environmental impacts as faunal analysis is expensive because it requires taxonomic expertise.

Table 3-5 presents a short summary of the environmental programs reviewed (see Appendix for extensive summary), and identifies frequently-used parameters, as well as the effectiveness of monitoring programs undertaken to address potential impacts. Environmental monitoring programs are in many cases costly. Reducing the regulatory burden on shellfish enterprises and avoiding costly and redundant public expenditures on monitoring is important to balance against effective and adequate monitoring of shellfish installations. The most important stage of an adequate monitoring program is to establish substantial temporal and spatial baseline parameters in and around aquaculture leases. Subsequent monitoring can then be scaled back according to annual results of monitoring following shellfish aquaculture installations.

The most frequently used parameters in benthic environmental monitoring are: benthic macrofauna sampling, organic enrichment and sediment particle size. Of the latter, particle size seems to be the most efficient parameter to demonstrate an impact on the benthos. Accumulation of biodeposits or organic matter will result in a change of particle size composition under the farm. Organic enrichment levels and, quantification and biodiversity of benthic organisms have been found to vary seasonally in certain cases. Consequently, there is a need to have substantial temporal and spatial baseline data before monitoring a potential impact as results might reflect natural variation rather than an impact. Sediment analysis is preferable to benthic fauna as an indicator of environmental impacts as faunal analysis is expensive because it requires taxonomic expertise.

Table 3-5 Impact parameters sampled in environmental monitoring programs

Parameter	Effect to be measured	% impact	N times applied in lit.	Relative Cost (H/M/L)
Benthic macrofauna	Change in assemblage composition	43	14	H
Organic enrichment	Accumulation of organic matter- potential for anoxia	45	11	M
Sediment particle size	Accumulation of external matter	80	10	L
Redox potential	Indicator of the level of microbial activity in organically-enriched sediments based on oxygen levels	60	5	L
Chlorophyll-a	Index of eutrophication, but unlikely to be of value on an individual farm basis	25	4	M
Nitrogen levels in sediment	Accumulation of additional nutrients	25	4	H
Phosphorus levels in sediment	Accumulation of additional nutrients	33	3	H
Ammonia	Accumulation of additional nutrients	100	2	H
Carbon levels in sediment	Accumulation of additional nutrients	50	2	M
Sulfide- sediment	increased of organic activity	0	2	M
C/N ratio	Accumulation of additional nutrients	0	1	H
Oxygen	Potential for anoxia	100	1	L
Seabed assessment (video/photography)	Morphological changes in seabed	0	1	L
Silicate levels in sediment	Accumulation of additional nutrients	0	1	H
Superficial shear	Disturbance of surface sediment	100	1	H
Water turbidity	Increased of suspended matter	0	1	M

The current locations of proposed precincts in Jervis Bay do not appear to be a problem in relation to seagrass, although the hydrodynamics of bio-deposition should be considered in relation to neighbouring areas. There appear however to be a diverse number of soft sediment habitats under the lease areas, and these diverse soft sediment habitats should be considered in a stratified monitoring program. Redox potential has been used for sediment monitoring in a number of occasions; however values vary depending on sediment type (i.e. muddy vs. sandy). Consequently it is important to choose control sites that have similar sediment type. In addition certain sediment types hold specific fauna assemblages. Also studies that showed accumulation of organic matter, also resulted in large quantities of oxygen consumption or accumulation of ammonia in the sediment.

As a result of the wide variability in the effectiveness of the reviewed monitoring programs it appears that different parameters play different roles in different aquatic environments resulting in a need to collect extensive baseline data prior to developing aquaculture in a site. Then when farms are running they should be managed in such a way that both, financial viability and ecological systems are sustainable:

- -a sustainable farm will result in an income at least proportionate to any capital investment & labour
- -a sustainable site will contribute towards maintaining the ecological characteristics of the overall aquatic ecosystem on which the farm and other users rely upon

Based on the information gathered from this desktop study, it is recommended that prior to establishing any aquaculture enterprise in Jervis Bay, baseline studies (or initial monitoring sampling) will be carried out, which may include of the following: soft sediment habitat profiles and seabed characteristics, video, hydrodynamic studies and estimates of primary production, sediment chemistry and benthic monitoring. Baseline studies will aid in determining whether there is a change in the phytoplankton assemblages before and after farms are introduced, and whether there is any impact on nutrient availability for other species in the proximity to these farms. In addition, interaction with habitats surrounding the precincts should be considered in conjunction with the Jervis Bay Marine Park goals.

Environmental monitoring programs are in many cases expensive, and reducing the regulatory burden on shellfish enterprises and avoiding costly and redundant public expenditure on monitoring is important. Once the shellfish cultivation is established the license holder would be required to comply with the I&I NSW recommended monitoring program design based on TOC and benthic fauna. If monitoring programs shows that there are negligible impacts after the first 3 years of full scale production, there is potential to reduce the monitoring requirements and to quantify potential impact through low cost but high value methods such as photographic/video monitoring under the cultivation sites. By choosing a trigger variable and impact level, it is possible to infer related variables recorded during the baseline data collection, that might be worth monitoring only if a trigger variable shows an impact. Industry best-practices or Code of Practice (CoP) may also be developed to address concerns of acceptable management practices.

3.3 Risk Assessment of Bivalve Cultivation in Jervis Bay

Considering the key issues of environmental impacts and mitigation of shellfish aquaculture, impacts can be broadly classified into four main categories: those affecting the seabed, those associated with characteristics of the water column, those issues associated with impacts of fish and mammals, and those associated with spread of invasive species and/or disease. The nature and magnitude of environmental impacts will depend on local characteristics such as:

- scale of production
- type of cultivation system
- husbandry practices: stocking densities
- duration of operation
- assimilative capacity of the environment
- topography/bathymetry
- natural levels of sediment / organic enrichment
- seasonal variability of benthic communities

Potential ecological impacts of shellfish farming can be classified as follows:

- risk potentially affecting the seabed
- risk associated with the characteristics of the water column
- risk to fish and mammals
- risks related to spread of invasive species and/or disease

Here a preliminary risk assessment for extensive shellfish aquaculture in Jervis Bay is provided (Table 3-6). In contrast to other NSW EISs that only consider the potential for mussel production, this report recommends considering the potential for growing five other native bivalve species in Jervis Bay.

3.3.1 *Recommendations: Risk Assessment of Bivalve Cultivation*

In summary, aquaculture in the Bay is considered to be of low to medium environmental risk at the proposed scale of precincts, assuming that operations use sustainable stocking densities (see calculated retention times as provided in section 3.1), appropriate husbandry protocols and strict translocation and environmental benthic monitoring protocols. Beneficial effects related to aquaculture enterprises should also be considered (i.e., habitat creation, fish attracting devices) (Forrest et al. 2009). However substantial baseline studies are needed to:

- Further assess ecological carrying capacity in the location of the proposed precincts
- Establish spatially and temporally replicated baseline data for benthic parameters (invertebrates, sediment chemical and physical parameters) under and around the proposed precincts
- Establish adaptive monitoring programs that can trigger an increase or decrease in monitoring effort.

Table 3-6 Risk assessment of potential mussel cultivation in Jervis Bay

Area	Cause/Change	Issue/Impact	Result	Solution	Jervis Bay Case Potential Risk (High/Medium/Low)
Seabed	Habitat loss and benthic habitat alterations	1. Aquaculture infrastructure secured to seabed 2. Accumulation of predators and changes in benthic faunal assemblages (Bartoli et al. 2001; Beaumont, Gjedrem and Moran 2006; Bendell-Young 2006; Cigarria and Fernandez 2000; Dumbauld, Ferraro, and Cole 2000)	1. Loss of benthic habitat due to aquaculture infrastructure anchoring 2. Aquaculture in a new area may attract predators, commensals, and other species to new area where they do not aggregate normally. This may affect the balance and natural behaviour of species in the area.	1. Using environmentally friendly moorings 2. Arranging for benthic monitoring, management, and assessment. The benthic community structure could vary spatial and temporally.	LOW The draft AIDP has already identified for lease areas taking into consideration habitats in the surrounding area and other constraints to aquaculture in the bay.
	Biodeposition	Oyster faeces and pseudofaeces settling to the bottom (Dolmer and Frandsen 2002; Inglis and Gust 2003; Laffargue, Be´gout, and Lagarde`re 2006; Lewitus et al. 2001; Posey et al. 2004; Ruesink et al. 2006; Rumrill and Poulton 2003; Watson-Capps and Mann 2005)	Enrichment of seafloor	1.The greater depth increases the time required for sedimentation to occur and, coupled with localised flow, acts to disperse the sediment over a wider area, reducing any potential for impact. 2.Ensure farm is in a well-flushed area	MEDIUM Lease area depths are within the 10m contour and the bay is overall well-flushed , however tidal current values drop towards the lease location to 0.5cm/s [range 0.5-12cm/s] (CSIRO, 1989)
	Shell litter and debris from farm cleaning operations and flesh from mortalities may be dislodged during storms and harvesting, drop-off of associated biota/fouling fauna	Increased accumulation under farm of organically-based waste farm products (cultured organisms, shells, and other debris) (Mark and Harry 2004; Piersma et al. 2001; Whiteley and Bendell-Young 2007; Crawford 2003; Crawford, Mitchell, and Macleod 2001; Duarte et al. 2003; Dumbauld et al. 2001)	1. Clumps of shells beneath farms become colonised by other organisms and provide reef-like habitats, thus attracting small fish and mobile invertebrates. 2.Potential for attracting large numbers of predators (e.g., starfish, crabs, urchins)	1. Farm cleaning process frequency (e.g., 2 wks) based on characteristics of farm site 2. Manage waste sustainably – recycle and use by-products if possible	LOW If species are cultivated in closed cultivation units, they are less subject to predation and to becoming displaced from lines (e.g., floating bags, lantern nets). MEDIUM Increased risk if species are hang off droppers ??? Increased risk if cleaning/work farm operations are only based at the lease (i.e., no land-based shed)

Area	Cause/Change	Issue/Impact	Result	Solution	Jervis Bay Case Potential Risk (High/Medium/Low)
Seabed (cont.)	Sediment enrichment	Shift in composition of sediment dwelling biota and productivity (Wood and Widdows 2002; Beadman et al. 2004; Richard 2004; Roycroft, Kelly, and Lewis 2000; Dupuy et al. 2000; Feldman et al. 2000; Gangnery, Bacher, and Buestel 2001; Gangnery, Bacher, and Buestel 2004; Hilgerloh et al. 2001)	1. Under low energy conditions, organic matter is deposited on the seafloor and accumulates directly below the aquaculture structure or near to it, depending on the direction of the prevailing current. 2. Shift in benthic community from deep-burrowing species to surface-feeding opportunistic species 3. Presence of anoxic sediments, reduced dissolved oxygen related to organic matter oxidation, increased sulphate reduction	1. Manage stocking densities according to physical hydrodynamic characteristics - ecological carrying capacity 2. Monitor benthic ecological impacts	MEDIUM If stocking densities are maintained within the ecological carrying capacity of the lease area (i.e., according to the management plan). Currents in lease are weak and inconsistent.
Water column	Perceived change in water quality	1. Re-suspension and/or transport of solids from benthos 2. Depletion/ reduction of primary production food particles 3. Release of dissolved nutrients by culture species (e.g., nitrogen and phosphorus) as waste metabolites or indirectly from solid waste degradation (Lindahl, Hart, and B. Hernroth 2005; Nelson et al. 2004; Newell 2004; Ruesink et al. 2003)	1. Fine solids could be shifted larger distances 2. Suboptimal environmental conditions for survival of in-situ species 3. Unbalanced nutrient recycling process	1. Prediction of fine sediments by using dispersion modelling or monitoring 2. Maintain low stocking densities Cultivate in deep waters that have high flows 3. Prediction of nutrient dispersal and dilution	MEDIUM The overall lease area proposed is a relatively small portion of Jervis Bay; localised effects could be observed if densities are not kept low

Area	Cause/Change	Issue/Impact	Result	Solution	Jervis Bay Case Potential Risk (High/Medium/Low)
Water column (cont.)	Flushing rates	Low production, growth rates (Cheney, Suhrbier, and Christy 2003; Gifford et al. 2004; Pietros and Rice 2003; Rice 2001; Songsangjinda et al. 2000)	A heavily stocked farm combined with a poorly flushed area (e.g., water remains in the area for long periods) can cause changes in phytoplankton abundance and nutrient cycling. In some cases, this change could result in an outbreak of toxic red tide organisms.	Maintain stock densities under the ecological carrying capacity of the lease. Appropriate management plan: extend of changes in primary production will depend on size of the bay, extend of flushing and natural variability of primary production in space and time	LOW Experiment with various cultivation methods and husbandry procedures to maximise the harvest while maintaining the ecological capacity of the lease.
Water column (cont.)	Currents and flow	1. Transport of suspended matter, nutrients, phytoplankton and primary production from and to farm 2. Biological processes of farmed species (Banas et al. 2007; Baudrimont, Schafer, and V. Marie 2005; Holmer, Ahrensberg, and Jorgensen 2003; Mugg, Rice, and Perron. 2001; Smaal, Stralen, and Schuiling 2001)	1. If low currents, poor replenishment of food quantity and low dispersion of biodeposits, impacting the farmed species performance and benthic community 2. If strong currents, inappropriate condition for the cultivation of certain species	Predict lease carrying capacity and ensure farm does not cause unacceptable ecological impacts	LOW Flows in the lease area are slightly low with potential for localised depletion and benthic impact. Only suitable for low density farming or spat holding
Water column (cont.)	Effect of farm structure	1. Change of the local hydrodynamic processes: Water movement restriction/ modify general circulation (e.g., flow direction and velocity) 2. Limiting habitat access (fish spawning aggregation sites, breeding and foraging sites) (Newell et al. 2004; Nizzoli, Bartoli, and Viaroli 2007; Nizzoli et al. 2005; North, Chen, and R. R. Hood 2005; Nunes, Ferreira, and F. Gazeau 2003; O'Beirn, Ross, and Luckenbach 2004; Paterson, Schreider, and Zimmerman 2003)	1. Localised effect -poor nourishment of farmed species 2. Change of ecological processes	1. Need for appropriate site selection 2. Need for appropriate cultivation system (e.g., long-line system) 3. Monitoring of the in-situ habitats and local organisms	LOW AIDP recommends cultivation based on long-line systems as they are less obtrusive and more adaptable to wave climatic conditions

Area	Cause/Change	Issue/Impact	Result	Solution	Jervis Bay Case Potential Risk (High/Medium/Low)
Other impacts:					
Impacts on local fauna and flora: Seagrass meadows Seabirds Fish Marine mammals	Injured or damaged endemic species	1. Attracting predators 2. Cultivation infrastructure secured to seabed or shading ecological important benthic habitats	1. Potential entanglement/ entrapment of organisms 2. Change of benthic habitat/ species	1. Entanglement protocol may be suggested 2. Code of best practices or other EMS document	LOW AIDP selected lease areas far from ecologically important habitats, fish recruitment zones, and marine mammals grounds. Non-fixed infrastructure will mitigate potential entanglement.
Invasive species	1. Biofouling 2. Creation of novel habitat 3. Biosecurity (pest/exotic spp)	1. Competition for food 2. Opportunity for exotic/opportunistic species to settle 3. Translocation of spat or juvenile if locally not available	1. Effect in the balance and natural behaviour of species in the area 2 & 3. Spread and competition of exotic species	1.Sediment removal or cleaning procedures (e.g., defouling of structures and stock) should be done in a manner that minimises environmental and amenity impacts 2. Translocation protocols	MEDIUM Spat and juveniles will need to be brought into the bay from estuaries or hatcheries near-by. If an appropriate translocation protocol is followed, this risk should be minimised. Frequent cleaning of farmed species will reduce fouling biomass and reduce intra-specific food competition.
Introduction of disease and parasites	1. Biosecurity (transfer disease/ pathogen) 2. Cultivation /husbandry process (e.g., Seeding Pearl oysters)	1. Stressed cultured species at high stocking densities. may become stressed 2. Risk that endemic but translocated organisms may carry pathogens that could be transmitted to populations that have not been exposed to it previously and have no resistance to it.	1. Stressed animals become more susceptible to disease. 2. Parasites from farmed species could be transmitted easily to wild stocks with consequent serious impacts.	1. Keep low stocking densities 2. Husbandry and translocation protocols	LOW Disease outbreaks could be minimised by not stressing the cultured species- e.g., supplying optimal environmental conditions for growth, high food levels, and low stocking densities
Genetic interactions with wild populations	Farmed species originate from selective breeding program	Potential impact of the wild population dynamics	Genetic disruption of endemic populations	1. Appropriate design of breeding program 2. Proportion of farmed oysters are generally lower than wild so it is impossible to change the genetic pool over a short period	LOW Reliable breeding programs in place Low volumes of cultured species vs. wild species

4 SOCIO-ECONOMIC FACTORS

4.1 Overview of Socio-economic Factors

The following discussion is intended to provide a framework for examining socio-economic considerations in a future EIS for Jervis Bay shellfish aquaculture. The goal herein is to provide recommendations for an approach within that EIS which could provide accurate economic forecasts of production values which will affect both the choice of species cultured as well as the production methods chosen. This differs from the original project objective to “make an independent socio-economic assessment of suitable aquaculture enterprises in Jervis Bay”; the difference in objective reflects the limited time and resources available to the current project.

The Twofold Bay EIS defines socio-economic impacts as aquaculture’s potential impacts to viewscapes, commercial or recreational fishing, recreational boating, and other water-based activities (Table 10). The Twofold Bay EIS also considers local needs for employment and tourism enhancement. These factors are similar between Twofold Bay and Jervis Bay, and thus do not reiterate them in detail in this report. However, a framework is suggested for analyzing a range of socio-economic factors as pertinent to Jervis Bay (Figure 6). As many resource-use conflicts and site selection criteria have already been accounted for in the JBAIDP, Figure 6 highlights the items which are relevant to the discussion and recommendations in this section.

Table 4-1 Description of socioeconomic impacts in Twofold Bay EIS as relevant to Jervis Bay

Potential impacts on	Relevance to Jervis Bay
Commercial fishing	Yes
Recreational fishing	Yes
Commercial shipping	No, but Naval operations need to be considered
Yachting and recreational boating	Yes
Other water-based activities	Yes
Land-based activities	Yes
Regional tourism	Yes
Regional employment	Yes
Cultural and heritage significance	Yes, in particular, consultation with Aboriginal communities

In the following section, further information is provided about potential economic considerations for production in Jervis Bay, while also acknowledging the limitations that make economic valuations and cost-accounting difficult. Also included is a brief discussion on non-monetary values such as aesthetic or recreational values, access to live seafood, or educational potential which will relate to the ability to garner public support for different forms of aquaculture production. Finally, information is provided about preliminary stakeholder consultations. An overview of the consultations is provided, while stressing the need for further work to identify potential stakeholder concerns about conflicts between diverse uses of the bay. Several factors, such as leasehold siting criteria to minimize conflicts, and other forms of public consultation are addressed within the JBAIDP, while others, such as discussions with community about business models that will maximize social returns as well as economic and biophysical productivity, would be valuable in developing an overview of the many factors affecting choices for resource allocation.

4.2 Economic Factors for Valuation Models: Species and Cultivation Methods

4.2.1 Economic valuation in Twofold Bay EIS

Economic data compiled in the Twofold Bay EIS will be less relevant to an EIS for Jervis Bay, as economic projections for the industry are very different in 2010 than in 1997. Further, the information compiled for Jervis Bay should include not just data for mussels, but also choices for a range of other species. A final consideration for differences in analysis are that the lease area identified in Jervis Bay comprises only half the lease area proposed in the Twofold Bay EIS, thus the scale of production will differ significantly.

In 1997 it was estimated that in Twofold Bay, mussel growers would produce 1,000 tons of mussels each year, thus providing employment opportunities for between 120 to 160 people (including casual employees). Although exact figures for multiplier effects were not considered in the Twofold Bay EIS, estimates included employment opportunities in the form of 150 or more additional jobs, with total value to the local economy in order of $5-10 million p.a. (1997 value, not adjusted for inflation).

Production in Twofold Bay has not nearly meet projected production targets identified in the original EIS, either because initial estimates were unrealistic or as a result of other unforeseen factors, including a lack of investment capital or production inefficiencies. Generating accurate production estimates for Jervis Bay will be important, and will require careful assessment of a number of additional factors that were not necessary to consider in the Twofold Bay EIS. The first criterion which will affect the viability of Jervis Bay as a production site is the choice of species cultivated and cultivation methods (this was assessed only for mussels in Twofold Bay). Economic value will also be reflected in operating margins based on the costs of capital infrastructure and production efficiency, which will have changed significantly since 1997. Further, an economic assessment will need to focus on both production costs and returns in such a way as to allow for a reasonable range of operating margins under conditions of uncertainty within current and future markets, and thus will require knowledge of market trends. In the following sections, the development of a strategy is described in more detail, that will account for these factors when estimating potential economic value for a range of species and production conditions.

4.2.2 Recommended economic approaches

A number of economic analyses have been conducted in NSW on profitability of different aquaculture species, and the methodologies used in Treadwell (1991) and subsequently Weston (2001) provide a potential framework for analyzing cost-benefit ratios and risk parameters for production in Jervis Bay. The data in these studies to derive values for aquaculture production is out of date, as production

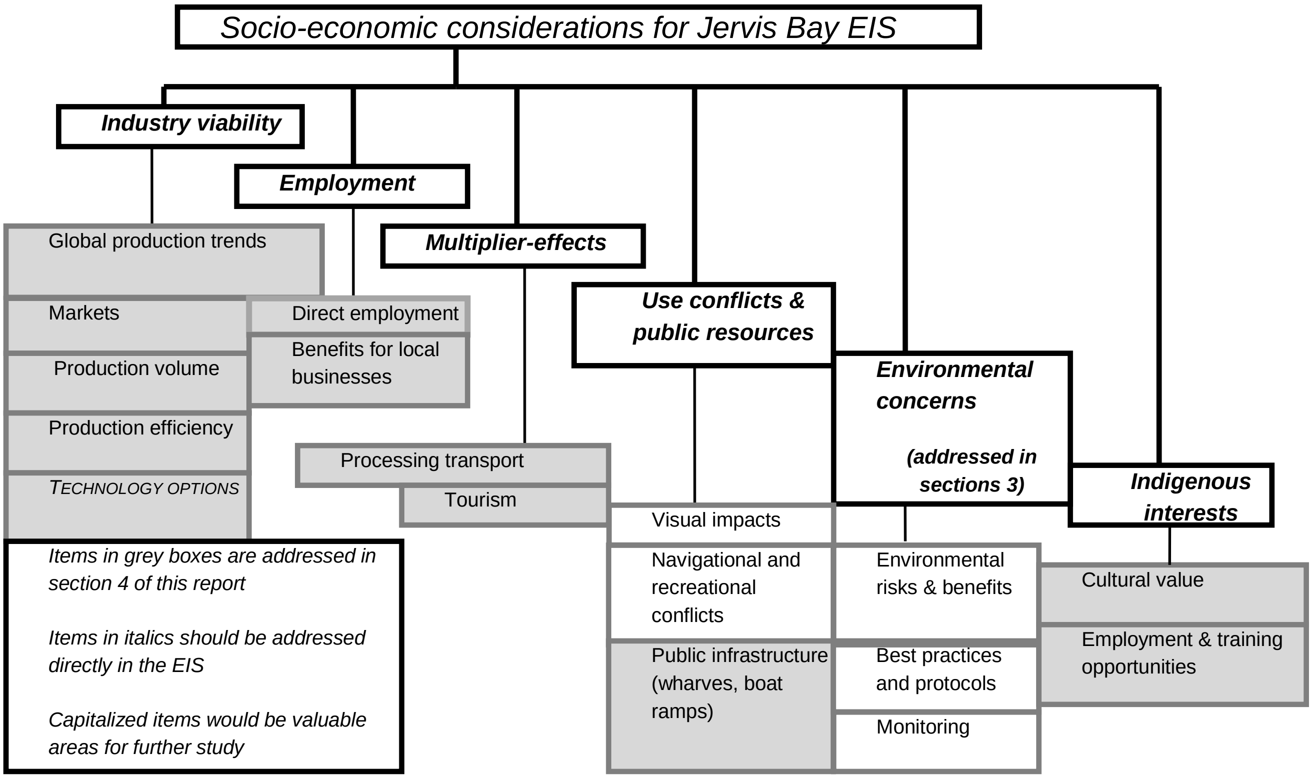

Figure 4-1 Overview of considerations for Jervis Bay EIS

techniques, costs, and market values have changed, but the economic assessment methods still apply. Cost-benefit analyses are subject to underlying biophysical and financial assumptions, so clearly forecasting returns will vary according to the unique circumstances of the investment, particularly site characteristics, species cultured, technological production efficiencies, and management expertise. However, overall values derived from these types of models will be useful in establishing estimated production values for Jervis Bay. In the following sections, these factors are discussed in relation to business models and choice of species cultured.

Factors considered in Treadwell (1991) and Weston (2001) can be used to generate economic valuations and risk parameters for potential aquaculture enterprises in Jervis Bay at a range of production volumes and for different species. The models provided in Treadwell (1991) and Weston (2001) are similar to other valuation models for which market software is available. Collating current data and entering appropriate variables in valuation models will allow for generation of potential profitability of farms in Jervis Bay. The next section discusses how to generate figures for total value of the potential leases based on these models and information about production carrying capacity.

4.2.3 Production volumes

The leasehold area for cultivation in Jervis Bay as identified in the AIDP, is constrained in size by other stakeholder uses. The size of available lease area will potentially limit the choice of species and types of business models which will be most effective in maximizing returns. In section 3 of this report, potential ecological carrying capacity was calculated for the five species under consideration in Jervis Bay. Production carrying capacity estimates are potentially too complicated for initial data collection, but rough estimates may be useful, and the factors discussed in sections 5.1 to 5.3 may provide more information for further field trials and data analysis. The detailed calculations required to accurately determine optimal production carrying capacities are generally undertaken by industry after EIS submission and during investment and business planning stages, and are subsequently refined during grow-out operations. Therefore these values are not calculated as part of this assessment, as they are not generally considered within the scope of an EIS. However, their significance is mentioned because it will be important for the EIS to comment coherently on production carrying capacity in determining the relative economic viability of different species and production methods. The more accurate the predictions of production carrying capacity, and thus potential economic value of product, the more refined the economic valuation of potential from aquaculture in Jervis Bay.

The Twofold Bay EIS did not mention production carrying capacities, but because of the smaller, 24ha area allocated for production in Jervis Bay, it will be important for the EIS to comment coherently on production carrying capacity in determining the relative economic viability of different species and production methods.

4.2.4 Shellfish species

A second step in identifying economic returns will be an investigation of the specific species relative to profit levels in a range of market conditions. Treadwell (1991) and Weston (2001) provide economic information for a variety of NSW species based on an investment analysis using internal rate of return, net present value, and benefit–cost ratios. Since their data collection in 1991 and 2001, the shellfish market in Australia has matured significantly, but their methods could be used to produce new estimates for various species using a range of potential prices and production volumes. Risk parameters in these models allow for uncertainty, especially during start-up stages where there may be unforeseen operating costs. A sample of the type of information that could be collated for inclusion in models is contained in Table 11. Table 12 summarizes qualitative information about production viability for the five potential species considered in this report, including provided a basic overview of factors which may affect economic viability.

Inclusion of information on potential marketing and distribution channels as well as current market trends would be appropriate with the EIS. In addition, it would be useful to include more information about possibilities for branding and marketing Jervis Bay aquaculture products In order to achieve market price differentiation of potential species, as this price differentiation may not be significant as anticipated. The following section provides a brief overview of market considerations and potential risk parameters for the species under consideration. Attracting investment capital will be important to the viability of aquaculture operations in Jervis Bay, and therefore more detailed descriptions of market potential for each of these species would be invaluable in future reports.

Table 4-2 Sample data (mussel production) for inclusion in valuation model parameters

Size of mussel farm	Average farm-gate value of product	Production volume (tonnes/year)	Employment (FTEs)	Overhead	Multiplier effects	Risk
Farm A[1] 1800 ha	$1.50-$2.50/kg (wholesale)	5000 tonnes/year	32	Processing / packaging facilities / hatchery / fully vertically integrated	Significant (1.2 or 1.3)	Low (<1)
Farm B 50 ha	$5.00-$6.00/kg (direct sales)	200 tonnes/year	5	Pay for wharf access / 2 boats / few economies of scale but high market price	Low	Low (<1)

[1] Sample production data from farms, more farms would need to be sampled to generate overall estimates.

4.2.4.1 MUSSELS

In the original EIS conducted for Twofold Bay, it was estimated that if 80ha of lease were developed for grow-out, production rates for mussels could be in the order of 12 to 17 tonnes/ha/year, for a total of over 1,000 tonnes per annum. Values in the Twofold Bay EIS were likely derived from Treadwell (1991). However, production in Twofold Bay has not approached this level (pers. Communication Chris Boynton), in part due to mandated use of single dropper systems, lack of capital and development of the total lease area, and infrastructure issues. Efficiencies in mussel grow-out may be enhanced by increased intensity of restocking and use of a continuous dropper system. According to data from I&INSW, annual mussel production in Jervis Bay on a single raft between 1978 and 2007 averaged around 7.5 tons, ranging between 0.5 to 23 tons due to variable production effort, culturing techniques, and efficiencies. Thus, this production data is not necessarily indicative of potential productivity of mussels within the available lease area, and significantly higher volumes of production may be anticipated if better efficiencies can be achieved, and given the larger lease area proposed under the draft JB AIDP. However, these figures are indicative of the good biophysical conditions for mussel production in Jervis Bay. Current productivity figures from other countries such as New Zealand or Canada for mussels indicate an approximate value of $30,000 to $35,000USD farm-gate value per hectare of lease using a submerged dropper system, but these values are also reflective of high volume production and much lower prices for mussels in those markets.

Mussel prices are generally relatively low compared to other species ($1.50-6.00/kg), and successful enterprises generally rely on economies of scale. Increased mussel production in Tasmania and South Australia, as well as enterprises in Western Australia, indicate huge potential for this industry to grow, while also indicating that prices may fall in the near-term, as larger vertically integrated producers are able to supply the Australian domestic market with large volumes of high quality, deep-water mussels. New leases for mussel development in Victoria are pending and may also increase domestic supply. Spat from the Queenscliff hatchery or Tasmanian hatcheries may be required for an operation in Jervis Bay, as natural spatfall in Jervis Bay is known to be quite variable and translocation from Twofold Bay may be inadvisable. The availability of spat will be an important consideration if mussel farming is desired as a form of aquaculture development.

4.2.4.2 SCALLOPS

A number of scallop experiments have been conducted in Jervis Bay, all of which indicate that there may be good biophysical potential for commercial grow-out (Fuentes et al. 1992; Heasman et al. 1998; Jacobs 1983). However, there are some notable limitations and additional research would be required to evaluate suitability. As compared to colder waters, such as those in Tasmania, reproductive periods of scallops in Jervis Bay are short, a factor which contributes to variable meat quality (i.e., 4 to 5 seasonal spawnings from April through November). Scallops have limited tolerance for temperature and salinity fluctuations, and therefore longline ear-hanging or pearl nets would require siting of grow-out in adequately deep water and in areas with limited wave action. Previously, 20% to 50% annual mortalities were recorded in Jervis Bay when there was a wild fishery for bottom-grown scallops, but the factors accounting for these mortalities are unclear (Brown, Nudd, and Scarsbrick 1995). Therefore if scallops were a species of interest for grow-out in Jervis Bay, a multi-species farm that included mussel longlines or oyster cages towards the surface, and scallops on longlines below other species, might be one solution to maximize profitability from an available lease area. However, the 10m depth of the current lease areas may not be suitable, and bottom culturing in sediment using dive harvesting may not be economical. Currently, the economic returns from scallop farming are marginal, primarily due to high costs of production and competition from Asian producers who have lower infrastructure and labor costs. However, there may be intrinsic value in developing some scallop production to meet local tourism demand, particularly if scallops are co-cultured with other species and sold through similar supply channels to local restaurants. Multi-species deep-water farms that grow scallops with other shellfish and seaweed species are common in other countries, and scallops may be a viable option as a local specialty item in conjunction with other sources of farm revenue. Scallops may also have enhancement value if grown as part of reseeding projects, or if aquaculture-grown scallops are viewed as providing a spat source from which populations may regenerate in the wild.

4.2.4.3 PEARL OYSTERS

Pearl oysters have higher value than edible oysters, and cultivation methods are generally visually unobtrusive, thus indicating that Jervis Bay pearl culturing could potentially be economically viable in small lease areas, especially if developed as a unique tourism product. Pearl oysters have limited temperature range, and therefore grow-out would most likely only be seasonal in Jervis Bay, as a combination of a low bay temperature and a freshwater flushing event may be adequate to present unacceptable risk parameters for investment during winter months. The size, and thus market value of pearls from Jervis Bay, is likely to be lower than pearls produced in tropical growing regions, but the quality of production is unknown until field trials are conducted. There is potential for high economic returns from small pearl oyster operations, especially if there is potential to sell at $100-500 per pearl (Brown et al, 95). There is also the potential for marketing pearl meat, which reaches high values in the Asian market (e.g., $1oo/kg fresh, $400/kg dried; WA Pearl Producers, 2008). Pearl meat is sold at some restaurants in Sydney, although most pearl meat from Australia is exported to Asia. Water and meat quality testing for export sales of pearl meat is expensive for a small operator if volumes are not adequate for export or unless high prices and direct links to markets could be established. However, both the availability of local pearls and meat may be considered in assessing the tourism potential in Jervis Bay.

4.2.4.4 OYSTERS

Edible oyster production is the fourth largest Australian aquaculture industry. However, Sydney rock oyster production has declined from the 1970s onwards, and later stabilized. The industry is currently negatively affected in some areas by periodic outbreaks of two diseases, QX and winter mortality (Heaman, 2002). Nonetheless, the Sydney rock oyster is currently the main species of oyster cultivated in NSW, mostly in intertidal estuarine areas. As with many traditional and long-established fisheries, there has been slow implementation of new technologies (e.g., use of hatchery produced seed, mechanized sorting and grading). Most Sydney Rock Oyster cultivation requires routine access to inshore facilities (i.e., sheds), which would contribute to higher overhead costs at the Jervis Bay site. Further, the biophysical suitability of deep water sites in Jervis Bay are unknown for Sydney Rock Oysters, and several reports question their feasibility (Brown, Nudd, and Scarsbrick 1995), particularly since most farmers in NSW are generally cultivating in more estuarine waters. The relatively long grow-out times for Sydney Rock oysters also limit their profitability, thus increasing labor costs and risk parameters. Disease risks are also a significant concern, and risk parameters for Sydney Rock oysters due to QX and Winter Mortality may play a large role in determining profitability. Sydney rock oysters have relatively high farmgate market values ($6-12/kg), but are less efficient to produce than mussels, as mussels have shorter grow-out times and can benefit from a variety of production efficiencies, including lower labour and capital costs.

Although the production of Pacific oysters has proven to be more lucrative using triploid seed in other parts of Australia and in some NSW estuaries, Pacific oysters are not considered in this analysis as they are an introduced species and thus do not meet the requirements set forth by Marine Parks for aquaculture within the bay.

4.2.4.5 FLAT OYSTERS

Flat oysters present an interesting higher-value alternative to Sydney rock oysters as they grow to a larger size, have more rapid growth rates, and generally have higher market value (Hurwood, Heasman, and Mother 2005). Marketable flat oysters can be raised in 18 to 24 months of grow-out on suspended culture in sub-tidal leases (Mitchell, Crawford, and Rushton 2000; Heasman et al. 2004), which is less than the period required to achieve marketable-sized Sydney rock oysters. A small but stable wild flat oyster (bottom) fishery previously existed in Jervis Bay and was most productive along the eastern side of the bay (Brown, Nudd, and Scarsbrick 1995; Fuentes et al. 1992). Techniques for culturing flat oysters in suspended longline systems are successfully used in other parts of NSW, although further field experiments would be required to determine at what depth in the water column flat oysters would tolerate wave action and potential temperature and salinity fluctuations within Jervis Bay. Further information on the economic potential of this species would be important for analysis, as increased production of flat oysters may be a way to diversify the NSW oyster industry, and would likely result in natural restocking of Jervis Bay flat oyster populations for recreational fisheries and Indigenous use. Flat oysters may be affected by bonamiasis, a disease which affects flat oysters worldwide including in parts of Australia such as Victoria, Western, and Southern Australia. To date, the specific bonamia species which affects *O. angasi* does not appear to be a significant cause of mortality in NSW, but it should be considered when calculating the economic potential of this species and assessing potential risk tolerance of investors. Farm-gate values for flat oysters are increasing on world markets, and even though hatcheries in Australia have been capable of producing successful runs of flat oyster spat, it is unclear whether there is adequate domestic market demand for significantly increased levels of production of this species. There is currently some domestic demand, and strong international demand on Asian and European markets, but export may be unrealistic unless overall NSW production volumes can be increased, and consistency of supply is assured. The marketing of flat oysters will require careful supply chain management to ensure optimal pricing for this species, as they are currently sold as high-end specialty products, and managing supply and demand will be important in order to maintain their market value.

Table 4-3 Assessment of potential aquaculture species

Species	Biophysical potential	Tourism value	Enhancement value	Economic value
Blue mussels	Excellent	Good	None	Fair
Scallops	Fair	Good	Good – particularly for recreational fisheries	Fair
Akoya pearl oyster	Good	Good	None	Excellent
Sydney rock oyster	Poor	Nominal given existing production in nearby estuaries	None	Fair
Flat oysters	Excellent	Good	Good	Good

4.3 Economic Factors: Infrastructure and Efficiency of Operations

It is not surprising that the economics sections of many cost-benefit analyses for aquaculture production are very general in nature, given that the economies of scale achievable, operating costs, and productivity of any given site are highly variable based on the choice of production methods, local environmental factors, and a host of infrastructure related issues which will affect profitability. Nevertheless, there are two key factors to consider when estimating operating margins: direct investment costs (e.g., facility and start-up), and operating costs (e.g., production overhead) in relation to a range of potential market values of production.

4.3.1 Investment costs for on-shore facilities and utilities

Investment costs in Jervis Bay are potentially higher than other locations, because visually unobtrusive equipment installations may be more expensive to install, and current land-based infrastructure to support aquaculture production is lacking. Additional infrastructure considerations in Jervis Bay will include a necessary assessment of costs of on-shore facilities to support production. For instance, in Twofold Bay, there was an existing commercial fishing and industrial port, and thus adequate wharf infrastructure and a public access slipway allowing for small-scale operations. Currently, however, Jervis Bay has no public slipway or marina in place which could accommodate boats with more than 1m draft, whereas large-scale aquaculture operations generally require mooring of larger boats. Farming that uses traditional NSW methods for grading oysters, or for de-clumping and cleaning mussels, requires land-based warehouses for equipment, as well as mooring facilities for boats with water supplies, and power for refrigeration and machinery, even if value-added processing (packaging, branding) do not take place on site. In the case of both edible oyster and mussel production, the costs of paying for public slipway access and leasing adjacent industrial land would be required, and operators would need to include these costs in their business plans. Further costs may also need to be considered for installing on-shore infrastructure for more extensive processing of product, should that be desirable. This may change in future with further development of infrastructure for other purposes (e.g., tourism).

A number of models could be adopted in the absence of access to on-shore facilities. Small-scale production might use a medium sized trawl vessel equipped for socking and later harvesting of mussels if onshore handling of aquaculture product is prohibitively expensive. In Twofold Bay, the grower reported that they were not de-bysalling or packaging mussel product prior to sale, thus most functions could be accomplished on the harvest vessel. Slipway access was only required for final product handling and transfer to transportation networks, therefore allowing the operator to minimize capital overhead. However, such systems are in general relatively inefficient for post-harvest activities, and do not generally allow for the value-added markups which can be achieved through packaging and branding within a processing facility.

At a minimum, oysters grown subtidally and without the benefits of tidal flushing (e.g., estuarine waters or surface cultivation) need to be tumbled/graded regularly. Therefore, there would be a requirement for edible oysters cultivated in Jervis Bay to be brought onshore for regular handling, or in the absence of adequate shore-based production facilities, boats with capacity to house production equipment.

As existing shore-based infrastructure was in place in 1997 in Twofold Bay, the Twofold Bay EIS did not need to account for infrastructure requirements of different types of production. The availability of shore-based infrastructure will constrain or promote different types of production in Jervis Bay and should be considered in the EIS.

4.3.2 Available technology and operating efficiencies

A range of production technologies and systems are in use for each species under consideration. Current cottage-industry, labor-intensive production systems for Sydney Rock Oysters are difficult to compare with high-cost offshore submerged, anchored-platform technologies which could significantly increase production volumes and efficiencies within the available lease area. Clearly, before such infrastructure could be adopted in Jervis Bay, the availability of investment capital for installation of infrastructure and long-term returns on that investment, as well as a broad range of other factors (e.g. visual impacts, recreation values, fishing) would need to be considered for different technologies.

Before proceeding with business plans for development in NSW, more in-depth economic analysis would be valuable to assess production efficiencies with available technologies for species under consideration. Production costs and values per hectare for existing aquaculture enterprises could for instance, be further analyzed in regards to production time, labour, capital investment, and infrastructure costs, and it would be invaluable to contrast those values with international production data, where other technologies and systems are in use. Such a study would aid in the Jervis Bay analysis, but also help existing NSW producers assess competitiveness and efficiencies of production, labor costs relative to yields, and productivity of current husbandry practices. Such a study is beyond the scope of this report, and potentially an EIS, but would be invaluable for indicating where operating costs could be reduced, indicating how to maximize production efficiencies, potentially justifying investment in centralized processing and marketing, or determining whether it is worthwhile to invest in value-added production.

Although not directly within the scope of an EIS, it is suggested that available grow-out technology is an important factor to consider. Before proceeding with business plans for development in NSW, more in-depth economic analysis for the five species under consideration would be valuable to assess production efficiencies with available technologies.

4.4 Economic Factors: Markets

An understanding of markets and world seafood trends will aid in analyzing trends in prices and production. As these are key inputs into economic valuation models, information on markets and seafood trends is important to include in the EIS. For instance, the Twofold Bay EIS makes several projections based on market trends for mussel production, and aquaculture more generally.

Several factors will affect markets for Jervis Bay aquaculture products, the most important being domestic market prices and production volumes for the species under consideration. An example of the first consideration includes the fact that average prices for mussels in Australia are currently relatively high compared to international prices because of limited supply, but are likely to settle fairly soon to levels more consistent with international values. Current farm-gate prices for mussels on world markets are approx $0,70/kg, and producers in countries such as NZ and Canada have had to decrease their production costs in order to remain competitive under these market conditions (Globefish and FISHSTAT, 2008). Victoria and NSW, and some Tasmanian mussel producers appear to be currently receiving much higher farm-gate values for mussels (as much as $6/kg) as a result of local sales and proximity to large markets in Sydney and Melbourne. Such premiums on unprocessed live product are possible in the short-term, and may potentially be sustained through branding and value adding. As supply increases in a more competitive Australian market, however, wholesale prices are likely to fall. There is compelling evidence that South Australia and Tasmania will be able to increase volumes of shellfish production dramatically in the next five to ten years, causing prices to stabilize in a more mature market.

Although Australian producers have a competitive advantage through regulation of imported live seafood, this advantage does not protect them from softer markets when domestic supply of live product increases. Vertical integration has been a successful model for some companies in Australia, and is likely to become increasingly prevalent as a strategy for competitiveness in the shellfish market. It is likely that a few consolidated enterprises will become able to dominate the market by providing consistent volumes and quality at a competitive price, thus making it increasingly difficult for small-scale producers, even those only targeting local specialty markets.

The following facts, extracted from various sections of the draft FRDC Research, Development and Extension Strategy report, are important for understanding current Australian supply and demand for aquaculture products. The importance to establishment of a successful shellfish industry in Jervis Bay of the trends highlighted here is discussed in the following sections.

- The aquaculture sector is one of the fastest growing Australian primary industries, with volume of production increasing by 40%, and Gross Value of Production (GVP) by 19%, since 2000-01.
- Imports of edible seafood products have risen 46% by nominal value in the eight years to 2007-08.
- Australian seafood consumption continues to rise on a long term trend, up to 22 kg per head in 2008, from less than 10 kg per head thirty years ago in 1978. These trends broadly reflect the rise in seafood consumption across other OECD economies.
- Research shows that Australian consumers believe seafood is better for them than other foods, and that they want to eat more seafood. They prefer to eat local seafood, but are generally unaware that around 75% of seafood consumed in Australia is imported.
- While nearly 60% of consumers believe they are consuming too little seafood in their diet, only 21% of consumers eat seafood regularly.
- Australian fisheries, food and recreational value chains and markets are increasingly complex and dynamic. As with other high value consumer foods, seafood demand and use is driven by emerging global consumer demands that are as much driven by lifestyle and health as by the need for affordable staple food.
- Consumers are showing an increased preference for purchasing their seafood from supermarkets, and desiring pre-packaged and pre-cooked or ready-to-cook products

- Australian producers need to differentiate, manage and market product as niche seafoods wherever possible. To achieve this there must be an increasing focus on species attributes and capability to attract consumer awareness, interest and demand.
- The rise of consumer demand for seafood (currently 17kg/person annually in wild fisheries) must be met by other means, including aquaculture (currently only 8kg/head).

World shellfish production has increased from 1.5 million tons in 1970 to about 16.1 million tons in 2008 (Figure 8; FAO 2009). Increased aquaculture accounted for most of increased world production; by 2008, 89% of the total bivalves production was from cultured sources. To meet future global demand for seafood, it is estimated that aquaculture production will need to grow 70% to 90 million tonnes by 2030 (FAO, 2010). For Australia, the potential for growth in the shellfish production is significant, both for domestic markets and increased export sales. Although aquaculture production in Australia is growing in other states, NSW production has declined overall (Figure 9). Oysters are the principal aquaculture species in NSW, and production volumes have decreased over the past ten years to levels of approximately 4000 tons/annum (Figure 10; ABARE, 2010).

Australia is currently a net importer of seafood products (almost 40% of seafood is imported), and Australia has not kept pace with shellfish aquaculture production values in many of the other OECD countries of similar size and with similar populations or coastline areas (see Figures 11-14; ABARE, 2010). The shellfish aquaculture industry currently has limited production relative to national consumption, and there is also a very limited Australian presence in export markets, particularly with the most commonly farmed species such as oysters and mussels. Trade restrictions against importation of live product from abroad have created an isolated market that is currently unsaturated, and thus prices for most domestic Australian shellfish products are much higher than international market prices (GLOBEFISH 2009).

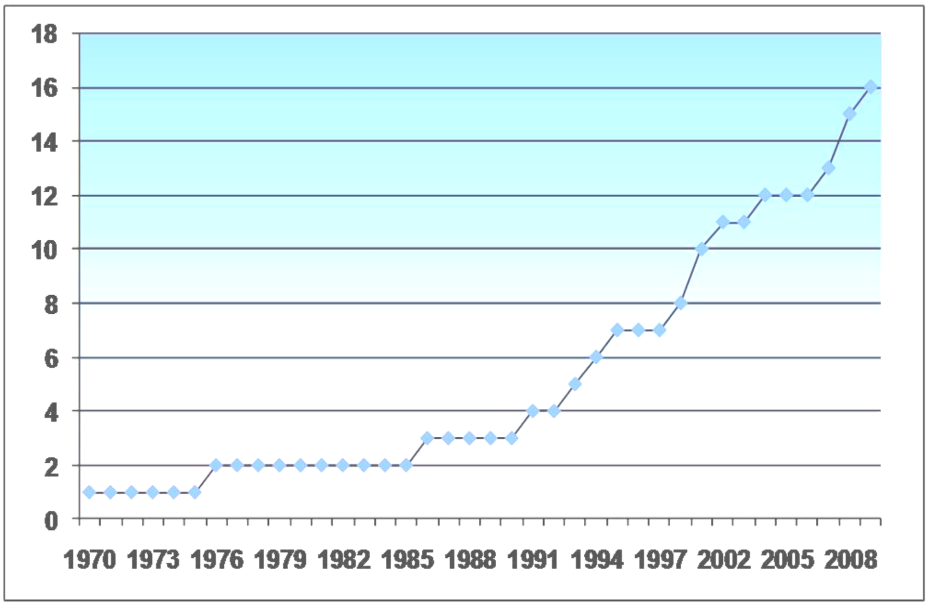

Figure 4-2 World bivalve shellfish production (millions of tons/annum)

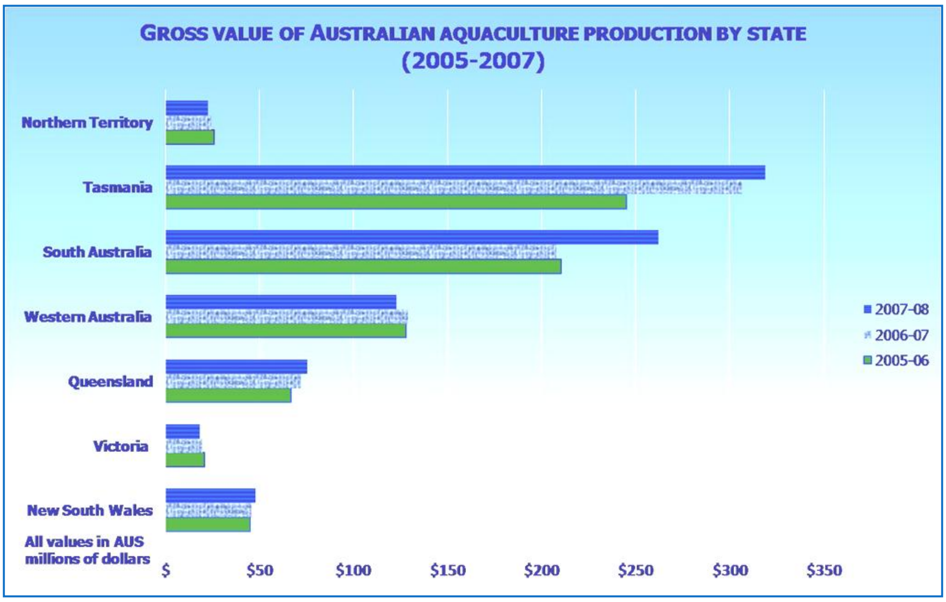

Figure 4-3 Australian aquaculture production by state

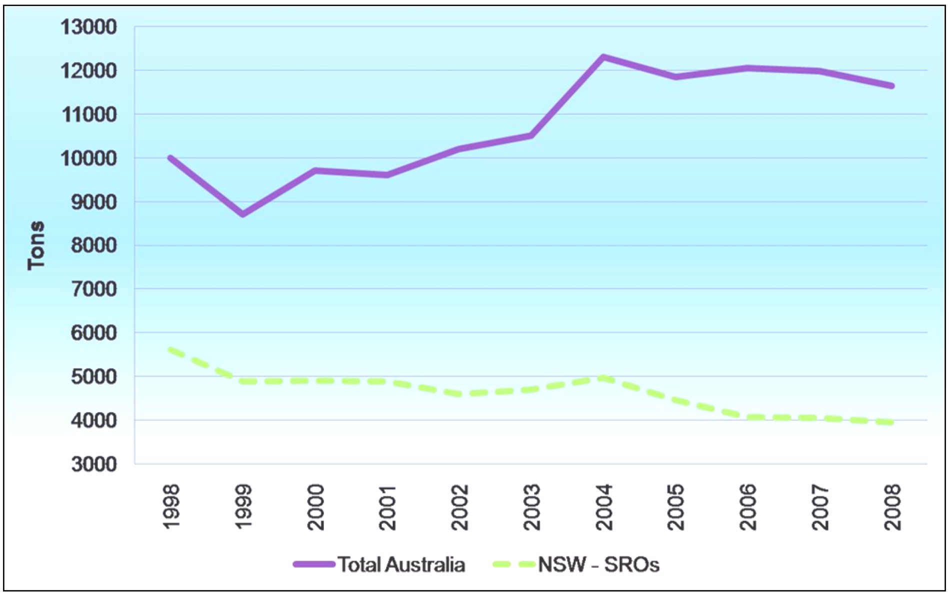

Figure 4-4 Australian and NSW oyster production (tons/year)

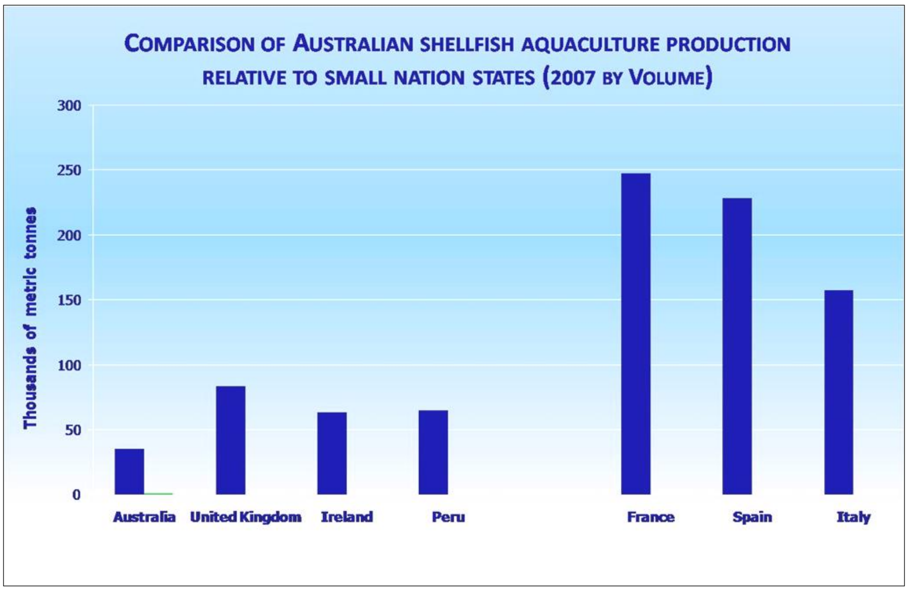

Figure 4-5 Comparison of Australian shellfish aquaculture production with small nation producers

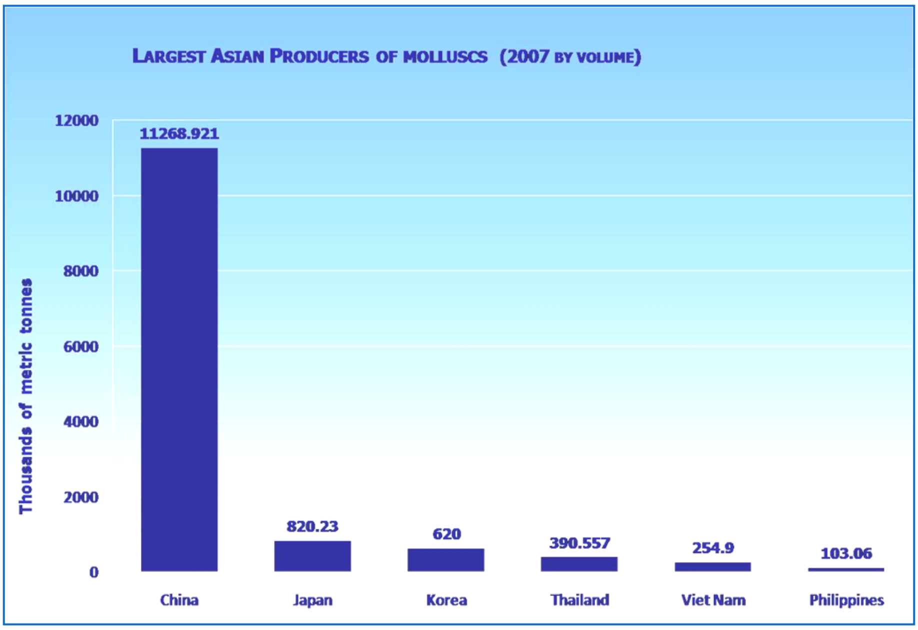

Figure 4-6 Largest Asian producers of molluscs

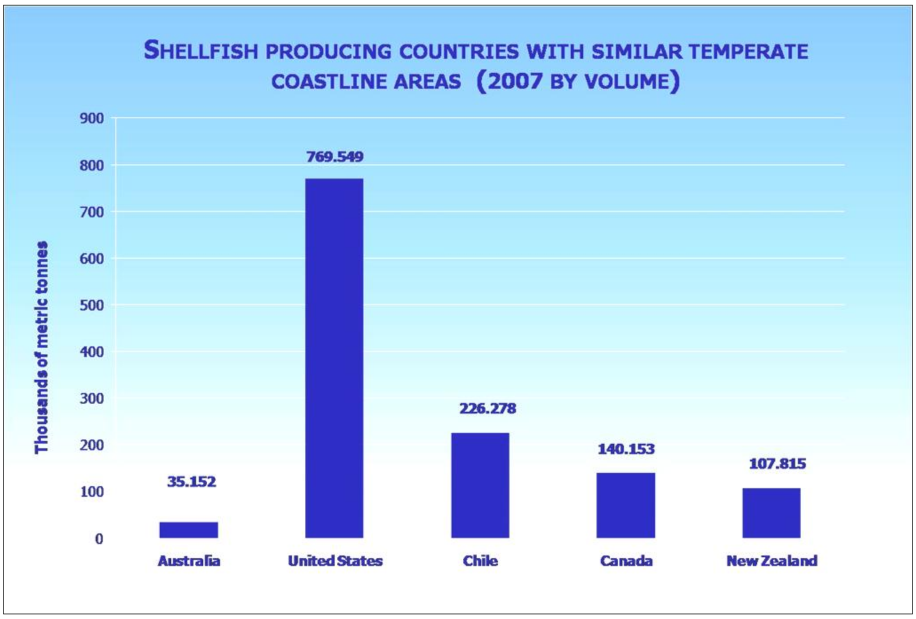

Figure 4-7 Shellfish producing countries with similar temperate coastlines

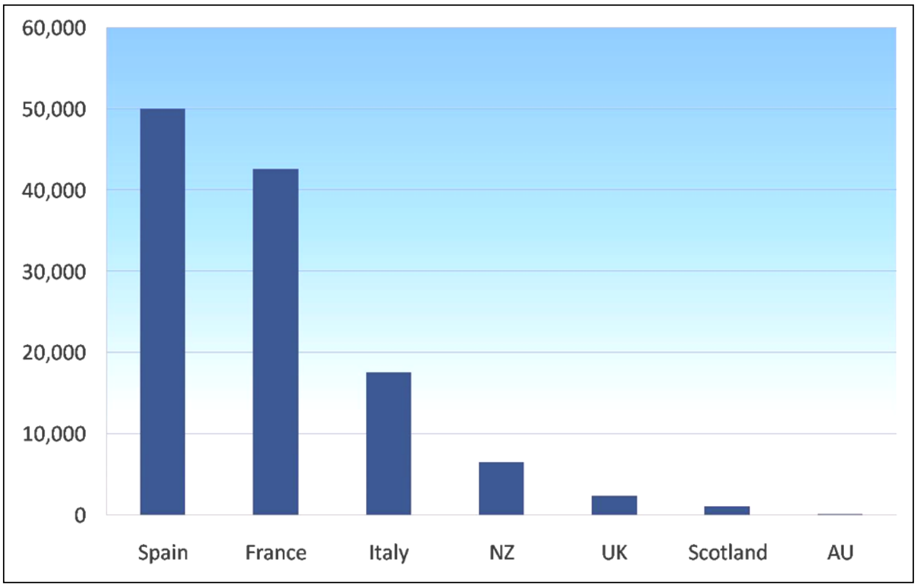

Figure 4-8 Shellfish production in tons/ 1000km of coastline

Domestic demand for seafood products is high and growing and supplies are currently limited. As supply increases in domestic markets, either through increased domestic production or from increasing competitiveness among imports, market price of shellfish in Australia will likely decline to be more in line with world prices. As a result, edible shellfish products are likely to shift away from being specialty higher-end commodities and become more affordable, and thus consumption will also likely increase through substitution effects. However, until critical supply thresholds are met in domestic production, thus allowing shellfish producers to benefit from economies of scale and supply chain efficiencies, production costs will remain high. It will be very important to examine these types of market trends in more detail, in order to get realistic estimates of production values and to determine which type of production and marketing will be most profitable if aquaculture is to proceed in Jervis Bay.

World trends for instance, are towards processed, pre-prepared, pre-cooked, and frozen seafood products available in supermarkets or through restaurant industry suppliers, and the availability of these products will ultimately reduce profit margins on live seafood, as live product has few attractive storage or handling characteristics. Live product is therefore a very limited specialty market and increasingly losing its competitiveness. Nitrogen freezing technologies for shellfish imports also allow for much cheaper substitutes for live products, and imports of frozen products (e.g., Chinese scallops or New Zealand mussels) will continue to drive prices downwards for most bivalve species. Currently, most Australian suppliers of bivalve shellfish are unable to meet supply requirements consistently and with value-added characteristics (e.g., packaging) that are necessary for supermarket or restaurant supply distribution. However, in both processing and distribution, the shellfish industry is moving rapidly towards vertical integration and large-scale centralized processing that can add value to raw product. Smaller localized and non-vertically integrated operations will need to account for these trends when assessing competitiveness of their products.

Market trends will be important in determining potential production values in Jervis Bay, in particular for determine which species and scale of production will be most profitable if aquaculture is to proceed. The Twofold Bay EIS provides significant information about market trends for mussels (from 1997) and those discussions should be extended to the five species under consideration in this report. Several market trends have been presented in this section which may be important to investigate within the context of economic valuations of potential Jervis Bay production.

4.4.1 Markets and distribution channels

The location of Jervis Bay has a competitive advantage for access to seafood markets in Sydney, as well as Canberra and Melbourne, since live product can be transported to any of these destinations within a day. Local seafood shops also sell large volumes of seafood products when tourists visit these areas. However, the relative ease of transportation and seasonal tourism advantages will need to be matched by efficiencies in production and strong emphasis on branding of the product, as it will be necessary to differentiate the product from other substitutes, particularly non-local imports. Supply linkages to higher-end markets are volatile in periods of economic downturn and cannot be relied on as an alternative to production efficiencies.

It is realistic to assume that export of product from Jervis Bay is unlikely due to the difficulties for small producers to enter or gain market share in world markets. Significant challenges for exporting shellfish products include:

1. Production with high enough profit margins to justify the additional costs associated with exportation (e.g., water quality testing and certification, transportation, marketing);

2. Efficiencies within the production cycle that will allow for competition on international markets;

3. High enough volume, consistency, and quality of production to meet domestic demand, and provide a surplus for export.

In light of these variables, it seems unlikely that product from Jervis Bay would have adequate volume of supply or price characteristics to warrant export.

A full economic analysis, including market analysis, is beyond the scope of the proposed EIS. However, basic and realistic estimates of production values based on economic valuation models will be necessary to assess the proposed development relative to its potential impacts. In addition to the use of valuation models, it will also be necessary to understand broad seafood production trends within Australia, as well as trends in world shellfish production as relevant for industry growth in NSW. The aquaculture industry in Australia is evolving rapidly, and current market values for shellfish products are unlikely to remain static, even over the short-term. Economic valuation estimates of the potential for aquaculture at Jervis Bay need to account for both projected operating margins and uncertainty in production and market conditions. Indeed, any economic assessment which bases feasibility calculations only on costs of production and current market prices, and fails to discount capital and financing costs relative to future markets, or to determine anticipated rates of return within reasonable risk parameters, will lead to inaccurate estimates of viability. Although some preliminary information about market trends has been presented, an assessment of the overall profitability of aquaculture in Jervis Bay will also reflect a wide range of localized non-market factors such as the existence of programs for investment in education, government-subsidized industry extension services, as well as continued regional tourism promotion. All of these factors will be important considerations for attracting investment capital for any proposed development.

Further research is recommended to quantify specific farm-gate values for all of the species under consideration relative to their cultivation costs. Information on farm-gate values and overhead costs can be used to discount capital and financing costs in economic models against future markets, and to determine anticipated rates of return within reasonable risk parameters for proposed lease areas. Although this is not explicitly in the scope of the EIS, it would aid in generating accurate economic values. The data collected could be used an input to models based on Treadwell (1991) and Weston (2001).

4.4.2 Benefits for local business and multiplier effects

Population growth in the Shoalhaven region is related primarily to the influx of retirees and growth of the tourism industry. Recreational fishing and access to fresh local seafood has appeal for both, and the Shoalhaven region is trying to develop a strong food and wine profile. With a decline in the commercial fishing sector, much seafood is now imported and there is opportunity for regrowth in the seafood production sector, particularly aimed at specialty markets. However, the limited volume of production possible in the current lease area allocated for Jervis Bay will not likely be able to profit from economies of scale or vertically integrated production, and a significant degree of product differentiation will therefore be required in order to maximize the value of production. Direct marketing connections with consumers and restaurants/food service industry (or tourist venues for pearl sales), will be most lucrative, as local products sold directly to consumers often have high mark-ups, with profit accruing directly back to the producer. Jervis Bay seafood products may sell for a premium if regional branding and identification of point of origin can be established. Value adding will be unlikely, but some form of product differentiation will be more lucrative than unbranded sales to wholesalers. Direct sales to the public and local restaurants in the vicinity of Jervis Bay under a regional brand would likely to be necessary in order to guarantee high enough farm-gate prices for economic sustainability over the longer-term.

Estimates of multiplier effects are important, as they may increase overall production values significantly. It will be important within the EIS to estimate multiplier values within valuation models. However, as several economists have discovered (Weston, 2001; Love, 2002), the overall value of Australian aquaculture, like other primary industries, is estimated and reported in terms of the gross value of production at farm-gate, without reporting sub-sectors of the industry including processing, marketing, retailing and freight transport. Therefore there is no concrete information on which to base these figures. However, in many cases, estimates would be adequate.

4.4.3 Community and Consultations

Community acceptance and support will also be crucial for success of any aquaculture operations in Jervis Bay. Although preliminary consultation with several stakeholder groups was conducted, including the Wreck Bay and Jerrinja Aboriginal Communities, Jervis Bay Marine Park, and Shoalhaven City Council, more in-depth community consultation will be required in compiling the EIS. Consideration of socio-economic factors that would maximize local benefits and minimize conflict with other uses of Jervis Bay would aid in addressing public, and potentially non-monetary, values associated with perceptions of aquaculture and leasing practices, such as environmental accountability, aesthetic and recreational values, public expenditures on tourism promotion, choices for resource allocations, as well as educational/training opportunities. There is a tendency in some EIS reports to limit socio-economic considerations to a basic cost-benefit analysis, although many other forms of analysis could equally be undertaken to examine the viability of shellfish aquaculture production in Jervis Bay. Direct economic calculations of profitability may not be able to fully account for employment or educational values, and indirect benefits accrue from projects such as this, including the development of 'social capital' which is equally important for long-term sustainability.

Using a modified cost-benefit analysis with the EIS, such as a Social Return on Investment (SROI), builds on the logic of a cost-accounting, but differs in its design by also focusing on optimising social and economic benefits, while mitigating environmental and other deleterious impacts. An SROI would be a valuable addition to the cost-benefit analysis, especially for garnering public support for aquaculture enterprises.

4.4.4 Indigenous organizations

While compiling this report, both organisations representing Aboriginal cultural interests and land and sea rights in Jervis Bay were consulted: the Jerrinja Local Aboriginal Lands Council (NSW), and the Wreck Bay Aboriginal Consultative Committee (Commonwealth). Both organisations were presented with an overview of the shellfish industry globally, nationally, as well as specific information about potential aquaculture development in Jervis Bay. The contents of the draft AIDP were summarized, and it was emphasized that the draft AIDP was intended to smooth the approvals process for establishing aquaculture in Jervis Bay.

Jervis Bay is culturally significant to local Aboriginal communities, with many spiritually significant sites occurring within and adjacent to the Marine Park, coupled with a continued tradition of cultural resource use. The population health profile indicates that the Shoalhaven is a relatively disadvantaged region of Australia, with population health statistics below the national average (PHIDU 2005). In part, this low average is due to the demographics of indigenous peoples, who make up approximately 4% of the population. The Aboriginal population (4% total) is slightly higher than other regional areas in NSW, and very high compared to NSW as a whole. Historically the Shoalhaven region has had low education levels and high unemployment rates among Aboriginal people, with less than half of indigenous 16 year olds attending full-time secondary education.

Feedback from the Jerrinja Aboriginal community was requested based on interest in indigenous shellfish aquaculture in Jervis Bay. The community expressed interest in employment from such an industry, and requested consultation to determine if there would be community support for extensive shellfish aquaculture, regardless of the lease applicant. Overall, both the Wreck Bay and the Jerrinja Aboriginal Communities indicated interest and support for shellfish enterprises in Jervis Bay, however, there was concern that indigenous enterprise opportunity would be disadvantaged. Frustration was expressed that an opportunity for development would arise, but that they would be ill prepared with the skill and knowledge required to establish aquaculture operations.

Both communities indicated they would be positive towards any commercial proponent with the intent to provide employment or other socio-economic benefits to the indigenous community, and this is particularly true in the case of Jerrinja Local Aboriginal Lands Council (JLALC) which understands that they have rights to areas of both land and sea in the proposed lease areas identified in the JBAIDP. JLALC has land claims established at coastal sites in close proximity to the proposed lease areas and would like to find out if and how they can make sea claims within Jervis Bay waters and be included in socio-economic benefits accruing from any shellfish aquaculture development. Similarly, Wreck Bay is interested in knowing if such opportunities might be extended to the Commonwealth waters in and around Jervis Bay. Further, both communities suggested that initiatives which encourage engagement with the indigenous population, including vocational training programs or enterprises which provide employment to local Aboriginal groups as a result of aquaculture development would be encouraged.

There is further engagement with the local indigenous communities and an investigation of the legal interests that these communities have in, and around, Jervis Bay during the EIS consultative process.

4.4.5 Marine parks and opportunities for public education

As noted, any aquaculture in Jervis Bay will also want conform to the Marine Parks mandate for enhancing conservation, recreation and educational values. In the United States, some communities have invested heavily in restoration of oyster beds to improve water quality in damaged estuaries and/or to promote artificial reef habitat for recreational fisheries (Rice, Valliere, and Caporelli 2000; Macfarlane 2003; Breitburg et al. 2000; Brumbaugh et al. 2000). Many of these projects have enjoyed considerable public support, and Jervis Bay leases could be developed as both an aquaculture site for enhancement and restoration projects (e.g., potential pipi nursery, or scallop or flat oyster reintroduction) while serving as an opportunity for public education regarding local food sustainability. One of the most important non-monetary benefits of this development may include diversification of local sustainable food production, at a time when consumers are increasingly seeking positive environmental attributes in their consumption patterns. Lease applicants could be encouraged to propose public education and green-marketing components within their business plans, and to provide evidence that they will include informative signage on farm installations and any shore-based facilities. Investment in educational signage, facility tours or public involvement in shellfish projects may have long-term value if it results in public support for local sustainable aquaculture and its products, as well as enhanced value for residents and positive tourism experiences.

An educational component associated with Jervis Bay aquaculture installations could potentially include reference to ecosystem services provided and demanded by aquaculture production Jervis Bay, and in so doing, be reflective of aspects of the ecosystem that are utilized for human well-being, either indirectly or directly through aquaculture's structures, ecological processes, or outflows. Final considerations in a socio-economic analysis could include other public values such as the satisfaction derived from being able to access fresh local seafood, and the indirect value this brings to a region. The ability to brand a local seafood product for restaurants, or to sell locally grown pearls, could increase the region's appeal as a tourist destination, but as noted, this value is difficult to estimate in monetary terms. In the current Draft Aquaculture Research, Development and Extension Strategy, FRDC suggests a need to significantly increase capacity for understanding the intrinsic and non-monetary values associated with seafood production, especially for understanding how value is perceived by non-commercial users and how this value can be increased (e.g., for recreational or tourism purposes). Aquaculture development should therefore not only consider factors that aid in maximizing economic value from aquatic resources, but also enhance the social and personal value derived from living in a region where a wide range of fresh sustainably produced seafood is available.

The EIS should include information about potential non-monetary values derived from aquaculture (e.g., value of access to local seafood, value of sustainable food production), as well as ecosystems services provided by aquaculture. Suggestions for educational components associated with aquaculture installations, or suggestions for native shellfish restoration projects.

4.5 Recommendations: Socio-economic Considerations

- Cost-benefit models, such as those used by Treadwell (1991), and Weston (2001) in previous reports on feasibility of aquaculture production in NSW, should be updated with current information and developed in basic economic modeling software to determine economic feasibility of a range of potential aquaculture species in Jervis Bay.

- The failure to provide accurate economic valuations of the potential for different species in Jervis Bay will undermine the purpose of developing an EIS, as these calculations are essential if investors and the public are to perceive aquaculture as economically viable and thus worthwhile. An EIS for Jervis Bay will clear some of the obstacles to establishing aquaculture in Jervis Bay, but it is suggested that informed economic projections within that EIS, will aid in attracting investment capital to any proposed development. This report includes recommendations for a range of data which should be included in an economic valuation model of Jervis Bay shellfish:

    - Profit levels for different species taking into account a range of market conditions (4.2.2)
    - Costs of on-shore infrastructure to support production or potential alternatives in absence of on-shore infrastructure (4.3.1)
    - Production costs and values/hectare of existing aquaculture enterprises in NSW as proxy for potential production values in Jervis Bay (4.3.2)
    - Integrated information about shellfish market trends (4.3.2)
    - Investment costs (capital and financing) relative to future markets (4.4.1)
    - Local direct-marketing opportunities for shellfish products and potential price differentiation based on this model (4.4.1)
    - Competitiveness of smaller, non-vertically integrated enterprises vs. larger centralized processing facilities and vertically integrated enterprises (4.4.1)
    - Production carrying capacity estimates for calculating profitability of different species in Jervis Bay, or in co-cultivating a range of species (4.2.3)

- Although not directly within the scope of an EIS, that available grow-out technology is an important factor to consider. Before proceeding with business plans for development in NSW, more in-depth economic analysis for the five species under consideration would be valuable to assess production efficiencies with available technologies.

- Aquaculture enterprises wishing to establish themselves in Jervis Bay will need to consider what type of land-based infrastructure is required, if any. The existence of a commercial wharf/jetty, and boat mooring facilities (e.g., marina), would facilitate development of aquaculture in Jervis Bay.

- Further research is also recommended to quantify specific farm-gate values for all of the species under consideration relative to their cultivation costs. Information on farm-gate values and overhead costs can be used to discount capital and financing costs in economic models against future markets, and to determine anticipated rates of return within reasonable risk parameters for the proposed lease areas. The data collected could be used an input to models based on Treadwell (1991) and Weston (2001).

- Market trends will be important in determining potential production values in Jervis Bay, in particular for determine which species and scale of production will be most profitable if aquaculture is to proceed. The Twofold Bay EIS provides significant information about market trends for mussels (from 1997), and those discussions could be extended to the five species under consideration in this report. Several market trends have been presented in this section which may be important to investigate within the context of economic valuations of potential Jervis Bay production.

- Preliminary consultation with Aboriginal groups indicates positive feedback about aquaculture production and its benefits, however, further consultation would be recommended with Indigenous groups in Jervis bay during the EIS process, particularly in regards to land and water rights as well training opportunities for Aboriginal people (5.5)

- Analysis using a Social Return on Investment (SROI) tool (5.1) could include estimates of non-monetary returns from local seafood production, including public benefits such as the availability of fresh local seafood; increased recreation and tourism potential; and public education value associated with aquaculture and/or native shellfish restoration projects (5.5).

- There is a need to significantly increase capacity for understanding the intrinsic and non-monetary values associated with seafood production, especially for understanding how value is perceived by non-commercial users and how this value can be increased (e.g., for recreational or tourism purposes). An EIS for Jervis Bay should contain specific recommendations for how aquaculture can enhance public values for sustainable food production, or enhance local tourism value in a “wine and seafood” circuit.

- The EIS could also include information about potential non-monetary values derived from aquaculture (e.g., value of access to local seafood, value of sustainable food production), as well as ecosystems services provided by aquaculture.

- Within an EIS, it may be relevant to include information about how educational components and signage about sustainability of local food production and ecosystem services provided by shellfish aquaculture could potentially reduce public conflicts. Suggestions for proposals for local community involvement in shellfish restoration projects (e.g., if scallops or flat oysters were grown to restore formerly overharvested species from the Bay) might also reduce public opposition.

5 BENEFITS AND ADOPTION

This report will benefit the process of finalizing the draft Jervis Bay Aquaculture Development Plan by I&I NSW. It will also provide background information for other government agencies, industry proponents and the local community in making more informed decisions and contributing constructively to future community consultation processes that will be required prior to establishment of aquaculture leases in Jervis Bay.

6 FURTHER DEVELOPMENT

The main recommendations in this report are provided in section 3, and include:

- Further assessment of the ecological carrying capacity in the location of the proposed precincts
- Establish spatially and temporally replicated baseline data for benthic parameters (invertebrates, sediment chemical and physical parameters) under and around the proposed precincts
- Establish adaptive monitoring programs that can trigger an increase or decrease in monitoring effort.

These must be addressed prior to establishment of aquaculture leases in Jervis Bay. In addition, full scale community consultation must be undertaken. The information provided here could be summarized in a format (e.g. Brochure or public meetings) that provides constructive information for informed contribution to the consultation process.

7 PLANNED OUTCOMES

The outcomes from this project provide a report that will contribute to the development of the Jervis Bay Aquaculture Development Plan, currently being drafted by IINSW (NSW Fisheries), for extensive shellfish cultivation precincts as planned. Specifically this report outlines the environmental (biophysical) conditions in Jervis Bay that may be suitable for various shellfish species, the environmental constraints and monitoring protocols. The beneficiaries of this report will be governance agencies responsible for the management of aquaculture and natural marine resources, potential aquaculture enterprise proponents to determine the suitability and viability of the proposed precincts, and the local community to inform them of extensive aquaculture operations.

8 CONCLUSION

In conclusion, this report supports the potential for extensive shellfish aquaculture in Jervis Bay for up to five native shellfish species. The scale of the proposed precincts seem to be well within the ecological carrying capacity of the Bay which as good flushing rates, and the substrate under the proposed precincts does not include any rock shore or sensitive seagrass habitats. There will still be requirements for benthic monitoring of the soft sediment substrates as well as other environmental considerations; recommendations are detailed in the report. In addition, the economic viability of shellfish aquaculture in the Bay has good potential, but a range of economic, production technology, species selection and market factors that need to be considered are outlined. Of note is that the local indigenous communities are supportive and would like to be able to be provided an opportunity for engagement with the industry, either through employment or associated activities.

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APPENDIX A – REVIEW OF ENVIRONMENTAL MONITORING PROGRAMS

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
McKinnon et al., 03	Blue mussels	Port Phillip Bay, VIC	Sediment particle size Redox potential TOC Benthic infauna & epifauna	Benthic grab samples & underwater video	Comparison under lease/farm vs 5, 25 and 50m away in direcction of prevailing currents	No major impacts as production levels are low (15-30t/ha/yr) % fine sediment decreases with distance from farm No differences in TOC and redox fauna vary across sampling sites in and out of farm Increase in predators under farm site
Crawford et al., 03	Blue mussels & Pacific oysters (3 long-lines)	East Coast, Tassie	Benthic samples-infauna Sediment deposition, sediment particle size, Redox values, Sediment sulfide concentrations, TOC water turbidity levels near the bottom	Sed sampling- core collection by divers; Underwater video of seabed	Samples along transects which ran across the farms, generally from 100 m upstream to 100 m downstream. Univariate indices: species richness measured as total number of species, total abundance, & the Shannon diversity index	Sediment deposition was significantly different BETWEEN the farms but NOT between reference sites Benthic infauna did not show clear signs of organic enrichment under farm, and neither univariate nor multivariate measures of benthic infauna were significantly different between sites inside and outside the farm, although they were different between farms. Redox in some farms was different at different depths Little impact overall- large variability within farms
Gifford, 06	Akoya Pearl oysters	Port Stephens, NSW	Chemical composition: TOC, nitrogen (N) & phosphorus (P) levels were analysed in sediment Benthic fauna (presence and abundance)	Divers collecting surface sediment samples and sediment cores	Sampling regimen: the number of controls sites used was increased from 5 to 8 to provide greater ability to detect impacts- based on pilot study Sediment samples from each site 4 x annually (irregular)- at each occasion and site: eight	NO differences between farm and reference- probably because stocking densities are extremely low

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
					sediment cores were collected for the various analyses	
Uni of Newcastle, Paspaley Pearls, FRDC (still in draft)	Pictada maxima, Pearl oysters	NT, WA	Chemical composition: TOC, redox, TN, TP, Silicate from core samples Benthic fauna from grab samples	Boat sampling: Core sampler and Van Veen grabber	one farm site (with 3 sampling sites and at each site, 3 subsamples) vs 4 reference sites (same replicates) Benthic fauna was preserved in 5% Formalin solution containing Rose Bengal Stain	Overall NO differences- (results still in draft)- some chemical difference in regards to TOC due to the shell under the farm; fauna diversity was slightly difference across reference sites, each reference site had their own fauna assemblages- difficult to compare NO differences because of high variability in benthic diversity within reference sites and large tides/ flushing at farms
Minister for Fisheries, 98 Stage 1 of EIS	Mytilus edulis, raft lease,Oman Pt	Eden, NSW	Preliminary seabed assessment by video and TOC samples under leases			TOC were low (<1%). Mussel bed has existed for 15yr. NO differences between TOC under leases and in controls. Current speed 0.1m/s (it has been estimated that if current >5m/s, no biodeposition)

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
Underwood 98, 02	Mytilus edulis-suspended culture-farm trial	Eden, NSW	Benthic fauna	Divers collecting sediment core samples	Pilot/ Preliminary study: Two sampling scales Variability was assessed among sites within the bay of the farm (10m) and across bays (100m) 2 sites on future farm site and 2 control sites 250m apart	NO evidence of any ecological impact on either the total number of different animal groups, number of individuals of the dominant taxa or the overall structure of the assemblages below the longlines in Twofold Bay = probably as a consequence of open bay well flushed There was a small amount of evidence indicating an ecological impact at the small spatial scale (mainly based on number of worms) under the farm site
Underwood, 06	Mytilus edulis	Eden, NSW	Based on Underwood 98: macrofauna	Divers collecting sediment core samples	Beyond-BACI sampling design and asymmetrical analyses of variance to compare changes in densities of taxa at several different spatial scales below farms with 2 controls (at each sampling area, 2 different sampling points and from each, 4 replicates)	After 18 months, NO evidence of impact on total number of taxa, nor densities of individual taxa. Short term temporal variations in densities at control sites- differ as much as farm benthic fauna
Cardno Ecology Lab, 09	Mytilus edulis	Eden, NSW	TOC Benthic fauna	Divers collecting sediment core samples	two leases and two control locations each. 6 replicates for TOC and 6 replicates for benthic fauna collected at each site. First analysis only 3 replicates are analysed for TOC	NO difference between farm and control sites- large variability in TOC so that all samples were processed.
Spencer et al, 97	Manila Clams (Tapes Philippinarum) - shoreline grow-out	Wales, UK	Sediment Fauna; particle content (size fraction). Organic content Chl-a	Sediment cores	2.5ys growth of clams in a plot at initial density 500m2 Plot= 10 x 1.5m 3 x 3 Latin Square design of 3 treatments: net-	Clam survival was poor. Final density 26m2 (0.78kg m2) Using the net- resulted in increased sediment rates, elevated ground, increased in fines and increase % org content. Netting resulted in high densities of infaunal

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
					covered plots of clams, net-covered plots w/out clams & control plots w/out netting or clams. Controls 50m away	deposit-feeding worms
Ysebaert et al, 09	Mytilus spp- bottom vs suspended culture	1. Microtidal (low-flow env, local deposition) - wind-driven system North Denmark; 2. Macrotidal (high-flow) The Netherlands 3.Upwelling estuary (North Spain)	Sedimentary env conditions: mud fraction; POC, PON, Phosp, Chl-a breakdown Macrofauna	Box core for sediment Diver & Video tracks for distribution of mussels and epibenthic animals	Fauna was classified into feeding groups Comparison of three sampling sites (farm with different environmental types) and controls	Significant HIGHER mud content, POC, PON, Phosp, Chl-a breakdown under bottom and suspended culture vs control Larger env cond in macrotidal cultivation due to hydrodynamic forcings Effect of suspended cultivation was influenced by topography and hydrodynamics- impact on benthic community structure due to biodeposition. Species composition changed from sandy spp to small opportunistic spp typical in org enriched sediment.
Hartstein & Rowden, 04	Blue mussels	Perolus Sound, Nz	Benthic impact (macroinvertebrate) at different hydrodynamic regimes (flow) Sediment grain size and chemical (org matter, POC, PON = N/C ratio)	Acoustic current meters at each sites Fauna- Van veen grab, Nutrients by Dietz grab, Dead mussel shells- counted	Three sites with different wave and energy currents. Seabed samples from inside and outside farm	Found DIFFERENCES in the macroinvertebrate assemblage composition inside and outside of mussel farm sites that experience low hydrodynamic energy, and NO detectable difference at the site with high hydrodynamic energy Total org matter levels were twice in farms, except in one location. Similar for C/N ratio. Sediment grain size was NO different. Macroinvertebrate abundance- differences from in and out in two farms but none in one of them At low flow, under farm high TOC and mussel debris. Polychaetes were abundant under lease Temporal differences in fauna but insignificant comparing across sites

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
Christensen et al, 03	Greenshell mussel Perna canaliculus- longline	Tasman Bay & Beatrix Bay-Marlborough Sounds: Nz	Benthic communities and mineralization in future mussel farms and in current farm. C/N ratio, porosity (water content) and Chl-a, Mycrophytobenthos, O2, NH4+ & NO3- by core incubation	Sediment cores and Van Dorn samplers by divers		Microphytobenthos added to primary production in water column. Denitrification rates were fueled by nitrate produced from benthos. Inorganic N taken up by benthic microalgae and nitrifiers/denitrifiers. Under farms: reduced sediment particle size, low MPB and macroinvertebrates due to high organic matter levels. Oxygen consumption was high in org sediment & high ammmonium effluxes than control sites Benthic fauna influenced by nutrients and microalgae
Forrest & Creese, 06	Pacific Oysters, Crassostrea gigas, intertidal	Nz;	Sediment grain size (clay/ mud) Organic matter Superficial shear Redox Macrofaunal	Sediment cores	Samples beneath and between racks vs controls Benthic species -analysed at family levels and in animal groups Impact of an on-going farm after 1-2yrs	Showed ENHANCED sedimentation beneath culture racks compared with reference sites. Topographic patterns more likely result from a local effect of rack structures on hydrodynamic processes than from enhanced deposition. Seabed sediments within the farm had a greater silt/clay and organic content, and a lower redox potential and shear strength. Species composition and dominance patterns were consistent with a disturbance gradient, with farm effects not evident 35 m away from the racks -Species-level Abundance-Biomass -Sediment shear strength was related to macrofauna- results in human-induced effect 'General group' classification vs family ID provides an appropriate and increasingly relevant tool for routine monitoring Differences detected during winter months were less pronounced than summer months

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
Giles 09 Weise et al 09	mussels, Mytilus edulis	Nz; Quebec (Canada)	Biodeposit Particle dispersal	Modelling (DEPOMOD fin-fish adapted for shellfish impacts)	Three sites with different hydrodynamic, model developed and compared with in-situ sediment rates collected in sediment traps	Alterations to the benthic community were observed at high biodeposition rates (N15 g m−2 d−1) Mussel biodeposits were predicted to accumulate within 30 m of the farms in the shallow depositional sites while being dispersed more than 90 m in the deeper dispersive site.
Mallet et al 06	Crassostrea virginca	New Brunswick, Canada	Redox Sulfide levels water =TSM & POM, Chl-a Sediment organic content Macrofauna Sediment deposition	Core samples	Monitoring period= 17 months Sampling every 6wks Two sites: floating bags and oyster tables vs 2 reference sites	Seasonal variations in redox and sulfide but NO sig differences between culture and reference sites. Organic enrichment from biodeposition under oyster table but not under floating system. Macrofauna under oyster table was high than under floating site in one yr but not the other Sedimentation rates varied significantly higher under oyster lines although organic levels were low
Bouchet_Sauritau, 08	Pacific Oysters, Crassostrea gigas, intertidal and subtidal	Pertuis Charentais, SW France	sediment - grain size, Redox Organic matter Macrozoobentho	Ecological monitoring- single vs and multimetric index Macrozoobenthos-based biotic indices and environmental sedimentary variables	Seasonal sampling Macrofauna- ID at species level and count. Use of environmental richness and abundance indices	IMPACT= Sediments affected by oyster biodeposits showed organic matter enrichment, and sediments from off-bottom culture sites had higher organic matter contents and lower redox potentials than sediments from on-bottom culture sites Oyster farming alters intertidal macrozoobenthic assemblages moderately, and off-bottom cultures cause more disturbance than on-bottom cultures Effect of hydrodynamic and seasonal variability was observed

Reference	Species	Area/country	What is monitored?	Method	Sampling protocol	Results
Stenton-Dozey, 99	Mussel, Mytilus galloprovinciallis, raft culture	Saldanha Bay, S. Africa	Macrobenthic composition (abundance and biomass) under 9 rafts	diver-operated suction sampler- samples retained in muslin bags and preserved	Analyses included ABC plots, hierarchical clustering and species diversity indices	Disturbed communities found under 78% of raft sites sampled. Disturbance & dominant opportunistic species changed from year to year, polychaetes and scavenging gastropods =most common. Disturbance- raft site more than raft age. Diversity indices showed marginal recovery after 4yr of raft removal Shift in benthic community due to organic loads from fish-factory effluent nearby

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